TEXT-BOOK

OF

NAVAL BOILERS

NAVAL BOILERS

A TEXT-BOOK FOR THE INSTRUCTION OF MIDSHIPMEN

AT THE

U. S. NAVAL ACADEMY

BY

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PREFACE.

This book has been prepared in order to provide a suitable text-book on the subject of boilers, the want of which has been felt for many years for instruction purposes in the Department of Marine Engineering and Naval Construction.

The rapid advances that have been made in recent years in the design and installation of boilers, both in the navy and merchant marine, have entailed considerable additional work on the part of officers attached to this Department in the production of lectures, notes, drawings, etc., to supplement the text-books in use and keep the instruction abreast of the progressive changes in boiler construction.

The occasional abandonment of an older text-book in favor of one of more recent date, while calculated to present the latest practices, has not resulted in completely satisfying our requirements, partly on account of the great scarcity of suitable text-books, all of foreign authorship, and partly on account of the necessity of supplementing any one with considerable matter to adapt its methods and practices to the conditions existing in our own navy. It was consequently deemed desirable to compile and arrange a text-book in accordance with the new conditions, and in continuation of the policy to design text-books, as far as possible, to suit the methods employed in engineering instruction at the Naval Academy, in class rooms, at drill, and on practice cruises at sea. The subject matter, therefore, has been confined as much as possible to United States naval practice, and excludes those topics which were already being taught in other branches in this Department. Details of theory, wherever their omission would not interfere with an understanding of a particular subject, have been left for future consideration in a post-graduate course.

Sincere thanks and appreciation are extended to Rear-Admiral George W. Melville, U. S. N., Chief of the Bureau of Steam Engineering of the Navy Department, and to his assistants, as well as to the naval inspectors of machinery at various manufacturing plants for their uniform courtesy and much valuable help; also to the manufacturers of the various types of the boilers described, to the manufacturers of the boiler fittings and attachments introduced in the text, and to the American Society of Naval Engineers for the generous gifts and loans of cuts. Grateful acknowledgment is also made for the excellent pamphlets and monographs prepared from time to time by the officers formerly on duty as instructors, and to those attached to the Department at the present time for valuable suggestions and assistance during the preparation of this book.

JOHN K. BARTON,
Commander, U. S. Navy, Head of Department.

U. S. NAVAL ACADEMY,
Department of Marine Engineering and Naval Construction, 1903.

The following books have been consulted:

Annual Reports of the Chief of the Bureau of Steam Engineering, Navy Department.

Machinery Specifications for U. S. Naval Vessels.

Journal of the American Society of Naval Engineers.

The Marine Steam Engine, by R. Sennett and H. J. Oram.

Practical Marine Engineering, by W. F. Durand.

Steam Boilers, by C. H. Peabody and E. F. Miller.

A Manual of Steam Boilers, by R. H. Thurston.

Constructive Steam Engineering, by J. H. Whitham.

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Marine Boilers, by L. E. Bertin; L. R. Robertson's edition and translation.

The Schiffsmaschine, by Carl Busley.

A Manual of Marine Engineering, by A. E. Seaton.

Marine Steam, by the Babcock and Wilcox Company.

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Steam, by Prof. W. Ripper.

A Treatise on Steam Boiler Making, by R. Wilson and J. J. Flather.

The Steam Engine, by D. K. Clark.

A Manual of Rules, Tables, etc., by D. K. Clark.

Mechanical Draft, by the B. F. Sturtevant Co.

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Gas and Fuel Analysis for Engineers, by A. H. Gill.

CONTENTS.

CHAPTER I.

GENERAL.

On board ship, the heat energy of the *fuel,* usually coal, but recently also liquid fuel in the form of petroleum refuse and coal tar, is transferred to water, which is converted into steam in the *boiler,* of shell or cylindrical and tubulous or water tube types. From the boiler, the steam is taken to the prime motor or *engine,* where its force exerts energy in the main or propelling engines, the various pumping, dynamo, hydraulic and other auxiliary engines. By means of these engines, the work required by the many necessities of a modern warship is done.

The work done by the main engines is utilized directly by means of the propellers in forcing the ship through the water.

In some auxiliary engines, such as many pumps, blowers or fans, anchor and steering engines, the work done by the engine is applied directly to the purpose intended.

In others, the work done by the steam engine, or *prime motor,* is transformed, by means of a *secondary motor,* into electric, hydraulic, or pneumatic energy, which in turn is exerted in the electric lighting circuit and motors, and in hydraulic or pneumatic engines.

To make the subject more intelligible, the steam generator, or boiler, with the fuels used, will be taken up first, and then the steam user, or the engine.

In order that a comprehensive idea may be obtained of the practical way by which the change of energy, from that of fuel to that of steam, is accomplished, a general description of the boilers used now, together with their nomenclature, will be taken up in this chapter.

The two kinds or classes now used are (1) the shell, cylindrical, Scotch, or water tank, and (2) the tubulous or water tube boilers. The first, hereafter, will be called *shell,* and the second, *tubulous* boilers.

The chief distinguishing features of these are as follows: In the shell boiler, a large quantity of water is contained in a closed

shell or tank, and the heat produced by the burning of the fuel passes *through* a number of tubes, called *fire tubes,* which are secured inside of this shell. In the tubulous boiler, a smaller quantity of water is contained in a collection of tubes, called *water tubes,* around the *outside* of which pass the products of combustion, and in one or more tanks or *drums,* which serve as collectors or reservoirs.

The differences in the various types of boilers in each of these classes will be taken up after the principles of combustion and evaporation, and the various fittings, which are common to all boilers, have been explained.

DESCRIPTION AND NOMENCLATURE OF A SHELL BOILER.

Plate I shows a front elevation of a *double-ended* shell boiler with four furnaces at each end, and Plate II, a side elevation of the same boiler, with the right-hand half shown in section through the center of the lower right furnace.

The shape of the boiler is shown by the large circle in Plate I and by the large rectangle in Plate II, and is, therefore, a cylinder, called the *shell,* closed at each end by a flat *head.* Built inside of this, at each end, are four *furnaces,* F, four *combustion chambers,* A, and four nests of tubes, T. The fuel is burned on the *grate* G, and the products of its combustion pass from F into A, through T, out of the boiler and into the front connection C, and up through the *uptake* U to the smoke pipe.

When steam is being raised in the boiler, the closed cylinder, or the *boiler,* is filled with water to some distance above the top of the combustion chamber A, the water thus completing surrounding F, A, and T, *i. e.,* all internal parts which are in contact with the fire.

The space left above the water level, called the *steam space,* collects and contains the steam as it is formed from the water. Near the top of the steam space, steam may be drawn off through slots in the dry pipe D, which connects with the *stop valve* W, through an opening cut in the boiler head. By means of W, the supply of steam to the engines is regulated.

The two furnaces on the right, Plate I, are shown with the *furnace front* R, *furnace door* Q, and *ash pit door* P, removed. Coal is put on the grate through Q, and the air necessary to burn it is admitted through small holes in R and Q, and through the

semicircular opening left by removing P. The grate consists of a series of *grate bars* G, supported on cross bars or *bearers,* and divides the *furnace flue,* which is the corrugated cylinder, into the *furnace* F and the *ash pit* F′. The lower part of F′ is frequently covered by a tray, or *ash pan* F″. S is a slicing door in Q for working the fire.

B is a brick *bridge wall,* which makes a back wall for the fire, and slightly reduces the outlet opening for the gases of combustion as they pass from the furnace to the combustion chamber.

C and U are secured to the outside of the boiler, and are, therefore, not an integral part of it. Access to the interior of C and A, and to the front ends of the tubes T, is obtained by means of the *uptake* or *connection doors* V, three of which are shown in place, the fourth one being removed from its hinges to show the front ends of the tubes. SD are soot doors in the bottom of C, and there are three sliding dampers (see Plate I), above V.

The pressure inside the boiler is shown by the *steam gage* SG, and any dangerous excess of pressure is relieved by the *safety valves* Sf.

The *water gage* WG, and the *gage cocks* GC, are used to indicate the safe water level inside the boiler. K and L are small valves on the pipes which connect WG to the top and bottom of the boiler. The supply of water to the boiler is regulated by means of *feed check* and *feed stop valve* E, a pipe connecting this with the *feed pump.*

Access to the interior of the boiler, at top and bottom, is obtained through the *manholes* M′. Three of these are shown closed, on the left of Plate I, by the *manhole plates* M.

H is the *surface blow valve* which connects, by the internal pipe and the *scum pan* SP, with the water in the boiler, and, by the external pipe running past J, with a discharge valve into the sea. J is the *bottom blow valve* which discharges into the same pipe and through the same outboard valve.

I is the *hydrokineter valve,* one at each end of the boiler, by means of which a circulation of the water can be set up.

Z, at the top of the boiler, is the *air cock,* and DC, at the bottom, the *drain cock.*

Y is the *dynamo stop valve.*

All flat surfaces exposed to pressure must be braced, stayed, or stiffened at regular intervals. The combustion chambers A,

being practically rectangular boxes of thinner plates than the boiler heads, need much staying and stiffening.

The flat heads are tied to each other by the *braces* O, of which there are, in the boiler shown, four horizontal rows above the tubes and the three braces surrounding the lowest manhole. Similar braces, but shorter, tie the remaining flat and unbraced parts of the head to the unbraced parts of the front plate of the combustion chamber. The backs and sides of this chamber are stayed to those of the adjoining one by *screw stays,* the flat bottom is stiffened by three *angle irons,* Plate II, and the flat top by the *girders* A′. The front plate of the combustion chamber is called the *back tube sheet,* and the middle plate of the head, the *front tube sheet.* These are tied to each other by the tubes, some of which, called *stay tubes,* are made heavier than the *ordinary tubes,* and are specially fitted as stays.

The boiler is supported by the five *saddles* N, which are built up from the hull of the ship.

The boilers are placed in *compartments,* the number of these and the boilers in each depending upon the size of the ship and the kind of boilers. A certain space, called the *fire room,* is left in each compartment at the furnace ends of the boilers, so that the fires can be worked. These fire rooms may be either *athwartship* or *fore-and-aft.* Communication between compartments is secured by *passages,* the doors between compartments being called *water-tight* doors.

The steam spaces of the boiler are connected by a system of *steam pipes* to each other and to the various engines. The uptakes of a certain number of boilers join in a common *smoke pipe.*

All parts of the boiler in contact with the fire on one side and with the water on the other are called *heating surfaces.* The rectangle enclosing the outside limits of the grate is called the *grate surface.*

DESCRIPTION OF A TUBULOUS BOILER.

Plate III is an outside view, taken at an angle, of the Babcock & Wilcox boiler of the "Alert" type, now installed with minor variations on the "Denver" class, "St. Louis," and other ships. Some of the valves and all of the pipe connections are omitted.

Plate IV is a side view of this boiler, with one side casing, protecting material, and side boxes removed. The steam drum, top connection box, mud box and furnace are shown in section.

The furnace is simply an enclosed space, not a large tube or flue, as in the shell boiler. It is bounded on the bottom by the grate, formed, as before, by the grate bars; at the back, by an inclined wall of brick; at the sides, by the *side boxes* I, below, and the tubes I′, above; at the top, by the lower row of tubes H, and a light roof of fire tiles, which is supported above these tubes and extends back for part of their length; and at the front, by the mud box M, the furnace doors and their frames. The ash pit is formed by the plates of the boiler foundation, and an ash pan at the bottom, ash pit doors closing the front.

There is no combustion chamber proper, except the enlarged space at the back of the furnace, into which the gases of combustion are forced by the fire tile roof on the tubes H. Here the gases mix and are more or less burned before they pass up among the tubes. The *baffle plates* B and B′, placed across the tubes, force the gases to cross the tubes twice more before they escape into the uptake U, thus mixing the gases below as well as increasing the time during which they are in contact with the tubes.

The boiler proper, that is the parts containing the water and which are under pressure, is made up of a collection of inclined *tubes* T, over the furnace, and a vertical row I and I′, at each side of the grate; the hollow boxes, called *front* and *rear headers*, R, R, and R, R′, respectively, which connect the vertical rows of tubes; the *mud box* M, and the *top connection box* M′, by means of which the several front and back headers are connected to each other at the bottom and top, respectively; and the *steam and water drum* Y, which, by means of a horizontal row of tubes, is connected to M′, and by short vertical tubes to the tops of the front headers R and R. The lower ends of all the headers are closed. There is thus formed a communicating space inside the various tubes, headers, boxes and the steam drum, the lowest part of this water space being at the bottom of the front side headers, and the highest, at the water level shown in the drum. A bottom blow valve m, is fitted to the bottom of each front side header. Above the water in the drum is the steam space. The drum is fitted similarly to the shell of the boiler previously explained, with the dry pipe O, water gages Q, feed check valves V, stop valve nozzle N, safety valves N″, manholes and plates in the heads, scum pan, surface blow pipe, and zincs.

The air for combustion, in this case, is admitted from the back of the boiler through ducts into the ash pits.

The pressure parts are surrounded by non-conducting material and the metal *casing* C, which is secured to the framework and the *foundation* d. In the front and back, the casing consists of the *front doors* E, and *back doors* E′, these giving easy access to the headers.

In the sides of the casing are the three rows of *dusting doors* D, through which the outsides of the tubes may be cleaned by a steam or air blast.

CHAPTER II.

CUMBUSTION AND FIRING.

The combustion of the fuel in a shell boiler takes place in the furnace and combustion chamber, and the resultant gases, mixed with some unconsumed fuel, pass off *through* the tubes and uptakes into the smoke pipe, and thence into the atmosphere.

In a tubulous boiler, there is a grate but no combustion chamber proper. The products of combustion are made to pass *around* the tubes and thence, in a more or less direct way, to the smoke pipe. The path from the fire to base of smoke pipe is, therefore, usually more direct and shorter than in shell boilers, although the tendency is to decrease the directness and increase the length.

The principle of combustion is the same, whether it is carried on in a shell or tubulous boiler, and whether the fuel is solid or liquid. As the methods differ somewhat with the kind of fuel used, it will be well to study first the chemical combustion of bituminous or "soft" coal in a shell boiler, the differences being easily understood as our knowledge of the arrangement of heating surfaces and the composition of various fuels increases.

Solid and liquid fuels consist chiefly of carbon, hydrogen and oxygen, in various proportions. The carbon, and that part of the hydrogen not combined with oxygen, are available for the heat-generating effect of the fuel. As the oxygen and part of the hydrogen of the fuel exist in the form of water, H_2O, and this is not advantageous for heat-generating effect, the heating value of the hydrogen is reduced by the amount of oxygen in the fuel in the proportion in which these two elements combine. This proportion is 1 : 8, or, the weight of hydrogen found to be present in the fuel by chemical analysis must be reduced by one-eighth of the weight of the oxygen. The heating value of the fuel, from its chemical analysis, can then be expressed by

$$\text{Heating value} = aC + b\left(H - \frac{O}{8}\right)$$

where a and b are the heating values of carbon and hydrogen, respectively, expressed in British thermal units.

Combustion is a rapid chemical combination or union of oxidizable substances with oxygen. This, with our fuels, means the union of the carbon and hydrogen of the fuels with the oxygen of the air, this union producing heat. Perfect combustion takes place when all the combustible constituents of the fuel are burned to CO_2 and H_2O.

To start combustion in a grate covered with coal, necessary heat must be brought in from outside, or, *the fire started*. After that, combustion is continued by the heat of the resultant chemical action. We can now take up the best method of burning bituminous coal, after a bed of *fire* has been obtained and this covered with a fresh supply. As the new coal becomes heated, its volatile gases, in various forms of hydrocarbons, are disengaged; those given off at first, or at the lowest temperature, contain the most carbon and form the smoke and flame-making parts of the coal. When these gases are exposed to a much higher temperature, they are decomposed and pass successively into lighter hydrocarbons, by precipitating portions of their carbon, until, at the temperature of low redness, there remains only olefiant gas, C_2H_4, common gas, CH_4, and free hydrogen. During these changes most of the smoke is formed. As the temperature rises, the olefiant gas loses half of its carbon and becomes CH_4, and at the highest furnace temperatures this gas may lose all of its carbon and change to pure H. During this *distillation* of the coal, the rising gases encounter and mix with the air coming in *above the grate* and pass into the combustion chamber. If now there is a sufficient quantity of air and the temperature in the furnace and combustion chamber is sufficiently high, the oxygen of the air will combine with the hydrogen and carbon, forming carbonic acid gas, CO_2, and steam, H_2O, respectively. Both gases are invisible. Until a sufficient quantity of oxygen has been taken out of the air to combine with all of the free hydrogen, no burning of the free or disengaged carbon takes place. It is, therefore, necessary that the air supply above the grate be sufficient, so that the combustion of the gases may be complete and useless loss of heat avoided.

Until all of the volatile gases have been disengaged from the coal, no burning of the solid part takes place, this changing gradually into coke, or fixed carbon, and the incombustible substances, or ash. To burn this fixed carbon air must pass through the fuel, and, therefore, come in from *below the grate*. If the conditions

are satisfactory, the oxygen, in its passage, will combine with the carbon and form CO_2, thus producing complete combustion. If the fire is too heavy (too thick), so that the air supply through it is too small, much of the CO_2 will take up another portion of carbon and be transformed into carbon monoxide, or CO. This result is incomplete combustion, and a great loss of heat follows, unless the CO can be changed into CO_2 before it leaves the furnace or combustion chamber. To effect this, air must be admitted *above the grate,* in addition to that required for the combustion of the gases of distillation.

It has now been seen how bituminous coal is burned in a furnace, first, by the distillation and burning of the volatile gases, and secondly, by the burning of the remaining coke or fixed carbon; that air is necessary both above and below the grate; and that the temperature must be sufficiently high for the combustion of the gases. This temperature is called the *ignition temperature* of the gases. Without oxygen no combustion can take place, no matter how high the temperature, and without the necessary heat neither the hydrogen nor the carbon will combine with the oxygen. Before showing how these conditions are met while firing, a short review of the composition of air, and of the chemical combinations of the elements which have been found present in coal, is necessary.

Air, from which the necessary oxygen for combustion is obtained, is a mechanical mixture, consisting principally of nitrogen and oxygen. The composition of air may be taken practically as 77% nitrogen and 23% oxygen, by weight, and 79% nitrogen and 21% oxygen, by volume. To obtain one pound of oxygen there will, therefore, be required, theoretically, 4.35 pounds of air. The volume of one pound of air, at 62° F. and atmospheric pressure, is 13.141 cubic feet.

To show how the two elements H and C are burned completely to the resultant gases, H_2O and CO_2, use is made of the law that the elements combine in the proportion of their atomic weights.

Two pounds of H will, therefore, combine with 16 pounds of O to make 18 pounds of H_2O, and 12 pounds of C, with 32 pounds of O to make 44 pounds of CO_2; or, 8 pounds of O are required for each pound of H to form H_2O, and $2\frac{2}{3}$ pounds of O for each pound of C to form CO_2. Or, in terms of air, to burn

1 pound of H requires $8 \times 4.35 = 34.8$ pounds, and

1 pound of C requires $2\frac{2}{3} \times 4.35 = 11.6$ pounds of air,

for complete combustion. Remembering that the quantity of H for heating purposes is reduced one-eighth by the weight of O present in the fuel, we get Dulong's expression,

$$\text{Air required per pound of fuel} = 11.6\ C + 34.8\left(H - \frac{O}{8}\right)$$
$$= 11.6\left\{C + 3\left(H - \frac{O}{8}\right)\right\}.$$

For practical purposes, the expression in brackets is assumed to be equivalent to 100 per cent of carbon, and 11.6 is taken as 12; the air required per pound of fuel is, therefore, taken as 12 pounds. But, in order to understand better the subject of air supply, the formula will be used here.

The composition of the average good steaming coal may be taken as 80% carbon, 5% hydrogen, 8% oxygen, and 7% of sulphur, water, ash, etc. D. K. Clark states that the fixed carbon remaining in the furnace, after distillation, averages 60% of the gross weight of the coal, or 20% of the carbon in the average coal is volatilized in combination with H. Of the 5% H, one part unites with the 8% O, and the other four parts are found partly free and partly united to the volatilized C. Enough air must, therefore, be supplied to burn 24% of gases and then 60% of carbon. Theoretically, all of the air for the gases should come in *above the grate,* while that for the carbon must come in partly from above, but chiefly from below the grate.

Quantity of Air Necessary Above and Below the Grate.—Although it is impossible to tell exactly in what proportions C_2H_4, CH_4 and H are disengaged above the grate, it may be assumed, for example, that the compound gases are generated in equal parts.

1 pound of C_2H_4 consists of $\frac{6}{7}$ C and $\frac{1}{7}$ H, and 1 pound of CH_4 consists of $\frac{3}{4}$ C and $\frac{1}{4}$ H. To burn these gases completely, after they have been separated through the effect of heat, will require

$$\frac{6 \times 11.6}{7} + \frac{34.8}{7} = \frac{104.4}{7} = 14.9 \text{ pounds and, } \frac{3 \times 11.6}{4} + \frac{34.8}{4} = \frac{69.6}{4} =$$

17.4 pounds of air, or a total of 32.3 pounds; or, for each pound of the mixed gases, 16.15 pounds of air.

For one ton of coal, 2240 pounds, and taking Clark's percentages as above, there will be required for its complete combustion

$$.60 \times 2240 \times 11.6 = 15{,}590 \text{ pounds below the grate;}$$

$$.20 \times 2240 \times 16.15 + .04 \times 2240 \times 34.8 = 7235 + 3118 = 10{,}353$$

pounds above the grate.

Or, in volumes,
15,590×13.141=204,868, say 205,000 cubic feet *below,* and
10,353×13.141=136,049, say 136,000 cubic feet *above* the grate.

These quantities represent the lowest limits in theory. But, from practical experience, it has been found necessary to increase these quantities, in order that a sufficient supply of oxygen may be obtained and that it may be thoroughly mixed with the gases. Under natural, or smoke pipe draft, this quantity shoud be doubled, and with artificial draft should be from nothing to one-half greater. It will be safe to assume an increase of one-half for artificial draft.

The smaller increase with artificial draft is due to the more nearly perfect mixture of the gases, and shows an economical advantage, for, as less air passes into the furnace, the reduction of the temperature of the gases will be less, and a smaller quantity of the inert nitrogen need be heated.

If then these increases are made in the figures found above, and 10% is added for some of the elements not taken into account and for variations in the coal, the approximate quantity necessary when burning this coal under artificial draft will be 340,000 cubic feet below, and 225,000 cubic feet above the grate, and under natural draft, 450,000 cubic feet below, and 300,000 cubic feet above the grate, in round numbers. For artificial draft, therefore, a total volume of at least 565,000 cubic feet of air would be needed, of which 40% is to be supplied *above,* and 60% *below* the grate.

In practice many deviations from the above are made, depending upon the type of boiler, the kind of coal, the method of firing, and on the views of the designer of the boiler and furnace and on those of the person in charge of burning the coal.

For anthracite coals, which contain a very small percentage of volatile gases, the air supply above the grates can be reduced to very little; for bituminous coals the supply must be greater.

Where little or no provision is made by the designer for air supply above the grates, the fires must, necessarily, be carried thinner for the same draft. On one of our ships, having no provision for air supply above the grate, furnace doors were kept open slightly, thus reducing the thick black smoke which issued before. This method, by admitting cold air in one large column, is harmful, and less economical than if proper provision had been made.

Furnace Fronts and Doors.—The different methods of admitting or supplying the air for combustion above and below the grate will

be better understood later on, but a description of the general construction of the parts that close the furnace opening will be appropriate here.

The structure that closes the furnace opening is called the *furnace front,* and in it are the *furnace doors.* It consists of two plates bolted to each other and to an intermediate semicircular skeleton frame, enclosing an air space, and has openings for the furnace doors, as shown by Figs. 9-1 and 2, pages 64 and 65.

R and R′ are the front and back plates and Q the skeleton frame. The sides and bottom of the furnace door opening are frequently separate from the frame, as shown in the figure; the bottom of this opening at P is called the *dead plate.*

The outer sheet of the furnace door I is flanged inwardly, so that its edge is a neat fit all around against the outer plate R. To the inside of the door, and separated several inches from it by thimbles, a perforated flat liner N is bolted. Frequently there are two or three of these liners fitted to a door. This liner, which is easily renewed, and the air space between it and I, protect the furnace door from the intense heat and partially prevent radiation. Stout hinge straps and a pivoted handle H are secured to I, the lugs for the hinges and for the two latches of H being riveted to R. The latch to the right keeps the door closed, and that to the left holds it open while firing in a sea-way. The rod K permits adjustment for the sagging of the door on its hinges.

A small opening, cut in the lower parts of I and N, permits the use of a slice bar without opening the larger furnace door, and is closed by a heavy, hinged *slicing door* S, which is kept shut by gravity.

In Figs. 9-1 and 2, the front plate R, and the furnace door are shown solid, so that no air can get through them from the fire room, as in this case the air for combustion comes from the back of the boiler and passes through the grate bars. The inner plate R′ is perforated, and openings in the bottom of the skeleton frame, and sometimes in the dead plate P, permit some air from the ash pit to enter above the grate.

With shell boilers using the closed fire room system of draft, and for running under natural draft, R and I are perforated with large holes through which the air is forced. Sometimes small louvres are fitted instead of the holes, thus allowing some regulation of the air supply above the grate. The other parts of the furnace front and door are the same as those just described.

Fig. 1 shows another form of front and door, as fitted to the Thornycroft boilers of the torpedo boats of the "Shubrick" class, working under the closed fire room system of draft.

I is the furnace door, which in this case has four liners N, the perforations in which alternate. The door is swung on an axis which is inclined to the vertical, and the lower end of which is set out from the furnace front further than the upper one. This arrangement makes the door self-closing. The slicing door S opens downward and is held shut by a catch; it is fitted with a liner. Door I is held shut by a pivoted catch secured to the furnace front at Y. This catch is disengaged by raising the cam handle H.

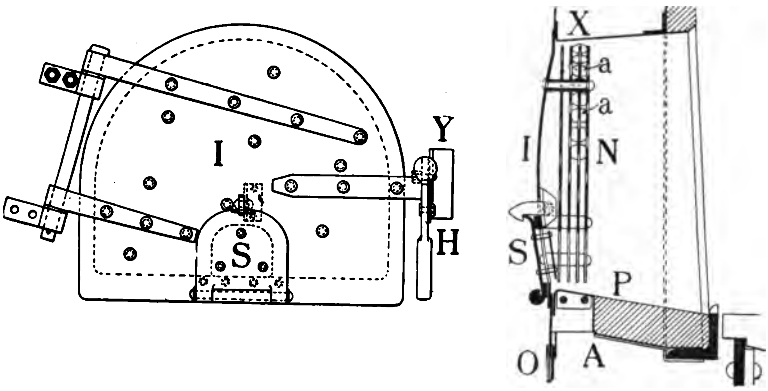


FIG. 1.

The air for combustion enters the space X above and around the furnace mouth, through swinging doors, and the ash pit A, through the doors O. A and X form a connected space, from which air is supplied to the upper part of the grate through sixteen 1-inch holes *a, a*. By being forced in between the liners, the air is slightly heated by the time it leaves the perforations of the inner liner.

It can now be understood that firing is not simply a question of throwing coal into the furnace, but that the fireman, to be efficient, must know where to put the coal, when to put in fresh coal and how much, and how to regulate the air supply. These requirements change not only for natural and artificial draft, but for the different kinds of anthracite, semi-anthracite, semi-bituminous and bituminous coals, and for different types of boilers.

Thickness of Fire.—The fire should always be uniform in thickness, otherwise the thinner spots will burn more rapidly and deprive

the thicker ones of the necessary air. If this is allowed to go on until a hole is burned through in one or more places, a humming noise will be noticeable, the intensity of which will depend upon the draft and the size of the hole.

The fire should not be too heavy, otherwise CO will be formed, and with insufficient air supply above the bars, may pass off in this state of incomplete combustion and thus cause a loss of heat.

The thickness of the fire cannot be fixed except by experience, as it varies with the coal, the draft, and the arrangement of the heating surfaces of the boiler. For average conditions and coal, the following approximations may serve as a guide:

With slightly bituminous, like some Welsh coals, 5 to 6 inches for ordinary, and as much as 12 inches for forced draft. Good firemen will, however, keep a thin fire even under forced draft. Semi-bituminous coals, like Pocahontas, 8 to 9 inches for ordinary, and 10 to 14 inches for forced draft. In general, it may be said that the thickness of fires in shell boilers is increased with the intensity of the draft, while in tubulous boilers the thickness does not vary with the draft. In the latter, the requisite amount of coal is supplied by more frequent firing, and the thickness, under forced draft, is usually not over 5 to 8 inches, when nearly all the air is supplied from below the grate.

Methods of Firing.—1. The method of banking up a supply of coal on the dead plate and letting it coke there, is sometimes economical with certain bituminous coals. The distilled gases are thus burned by the heat from the incandescent coke which has been spread over the grate. When the pile on the dead plate is coked (in about 20 to 30 minutes), or has stopped giving off volatile gases, it is shoved back and burned on the grate, the heat of its combustion helping to burn the gases evolved from the next supply of fuel. This plan is not always practicable, and care must be taken that the pile at the door and on the dead plate does not choke the air supply through the holes in the door and frame, as the gases will pass off unconsumed, unless the fire beyond should happen to be thin enough to supply the requisite air. If the fire in the back is covered with a heavy supply of fresh coal, the temperature will be reduced below that necessary to ignite the gases from the coking pile and cause waste.

This process, even when suited to the coal, is not applicable with strong forced draft, as there is no time for the proper coking of the

fuel. Rapid evaporation is wanted, and, therefore, a greater quantity of coal must be burned, although less economically.

2. Another method, where the furnaces are wide enough (as in tubulous boilers), is to coal one-half of the grate alternately, using the heat from the bright side to burn the volatile gases from the newly coaled or coking side. The same principle holds in firing alternately the adjacent furnaces which open into a common combustion chamber in shell boilers. In this case one fire is coaled, the gases being consumed in the combustion chamber by the heat from the bright fire in the adjacent furnace. From this follows the rule that no two furnaces in one boiler, at least in the same end of the boiler, are to be coaled at the same time. An extension of this rule is that the furnaces in one fire room shall be coaled in rotation, so that no two furnace doors of shell boilers (in eight or less furnaces) shall be open at the same time.

3. The usual method of firing the narrow furnaces of shell boilers is to spread a thin layer over the whole grate, keeping in mind the rule above in 2. The charge must be light and spread evenly over the grate, the time between charges ranging from 10 to 15 minutes for ordinary draft. The firing must be done quickly, so that the door will not be kept open longer than necessary. As it is easier for men to throw a heavy charge two or three times an hour than to put in six light charges, special care is needed to see that the firing is done often, lightly and quickly. The fire should not be disturbed or broken up oftener than necessary.

When firing the large furnace of a tubulous boiler, for economical results, under natural draft, about three or four shovelsful put on every 6 or 7 minutes and spread evenly over the greatest area possible has given good results. The coal used was excellent semi-bituminous, on a grate surface of about 46 square feet. With a greater rate of combustion, although not forced draft, the interval was reduced to 5½ minutes and a greater quantity put on each time. With a larger grate area, about 60 square feet, the furnace having four doors, two alternate sections were fired in rapid succession. The two other sections were sliced through the small slicing doors and leveled with a hoe. From 8 to 10 minutes after the first two sections had been coaled, the next two were charged. The coal was only a poor quality of semi-bituminous, containing considerable slate and clinkering badly.

Shorter intervals than 5 minutes between coaling are too hard on the firemen, except on very short trials.

Fine and Lump Coal.—With much fine or small bituminous coal, it will often be found economical to dampen the coal before firing, the loss by the waste evaporation of this water being more than offset by the saving in unconsumed carbon carried up through the smoke pipe, or dropping through the bars into the ash pit.

Lump coal should be broken up into pieces not larger than a man's fist, as the mixture of the air with the carbon will be effected more quickly and efficiently.

Bright Fires.—The fires should be kept bright and clean. With non-coking coal the surface must not be disturbed; with coking coal the surface must be broken up occasionally by the slice bar, used through the slicing door, or by the pricker. When looking at the fire from below through the ash pit, it should be bright and show no black spots. By a judicious use of the pricker, these spots, due to ash or unconsumed fuel, can be removed. Care must be taken that the end of the pricker does not go through the top of the fire and leave air holes.

Ash Pits.—These should be kept clear of ashes. Care must be taken not to get water in the ash pits of internal furnaces. Not only does the accumulation of ashes interfere with the draft, but, as a consequence of this, the grate bars are liable to be burned and fall down.

Cleaning Fires.—The pricker, with good coal, will remove most of the ashes and small clinker. When heavy clinker is left on the bars, as will happen with many kinds of coal and after long steaming, the fires must be thoroughly cleaned from above the grate. Depending upon the quality of the coal and the amount burned, cleaning fires will be necessary every 12 or 24 hours. As with coaling fires, the time for cleaning should be arranged so that no two fires in one boiler and in one fire room are cleaned at the same time. The time for cleaning by watches is usually marked on the connection door or front of the boiler, each watch being given an equal share of the work, if practicable.

The watch going off will allow the dirty fire to burn down, so that the new watch can start cleaning it at once. If uptake dampers are fitted for each furnace, the particular one should be closed while cleaning the fire; if none is fitted, the blower near that furnace should be slowed. As the cleaning interferes with the steaming of the boiler, everything should be done as quickly as possible.

Two methods are used. In one, the clinker and slag, and gener-

ally most of the fire on the front part of the grate, are hauled out by the hoe or devil's claw. Then the back of the fire is hauled over the fire remaining on the front of the grate and the clinker removed. The clean fire that remains is next spread evenly over the grate and a thin layer of fresh coal spread over this, the damper being then opened, or the blower run faster.

In the second method, one side of the grate is cleaned and then the other, the rest of the process being as before. In the large grates of tubulous boilers, it will be advisable to clean only one-half or one-third of a grate at a time, distributing the work through the watch.

As the hot clinker and coal are hauled and fall on the fire room floor, the intense heat is somewhat reduced by wetting them by means of the hose provided. This should be done as sparingly as possible, and care must be used not to get the water on the boiler fronts or in the ash pits.

Cleaning Tubes.—On long runs, the draft area and the efficiency of the heating surfaces will be materially reduced by the accumulation of soot and cinders. Not all of the heating surfaces can be cleaned under way, but the inner surfaces of tubes and the connections of shell boilers, and the outer surfaces of nearly all tubes and parts of the steam drums of tubulous boilers can be reached by a steam or compressed air blast. Like the cleaning of fires, this process interferes with the steaming of the boiler, and must, therefore, be done quickly and alternately for the different boilers. The fouling of the tubes can be ascertained by inspection; depending upon the quality and quantity of coal burned, cleaning will be necessary about every 24 or 48 hours.

Firing Tools.—The fireman's tools are shovels, short and long hoes, prickers, short and long slice bars, and devil's claws. The first two need no explanation, excepting that the hoes are moderately heavy for cleaning fires and lighter for hauling ashes.

Prickers are round bars with one end flattened and turned up at right angles, the bent-up end often having a stop welded on to prevent the flat end from entering the fire too far. The length of the flat end, or the position of the stop on it, will depend on the thickness of fire best suited to the coal used.

The devil's claw is something like an ordinary rake with five or six heavy prongs. It is not much used, most firemen preferring the hoe.

Slice bars are round bars with one end flattened, and a more or less rounded point, so that they can be slipped easily between the grate and the fire.

All of these tools have an elliptical ring turned at the handling end, as straight ends are much harder to handle.

To lighten the work while using long hoes in cleaning fires or in hauling ashes, a removable cross bar, called a *lazy bar,* is placed in supports fitted to the furnace door frame and to the ash pit.

Ashes.—In ordinary cruising, when using much fine semi-bituminous or bituminous coal, economy will often result if the small coal and ashes that have dropped through the grate are put into the fire again.

The ashes in the ash pit should be hauled frequently, and the ash and clinker from cleaning fires be removed from in front of the furnace to some place near the ash hoist or ash ejector, care being taken that they are not piled against any bulkhead plates. Boards, put against the bulkheads temporarily, make a good protection. When the ashes have been removed, the guard plates on the boiler front, the front of ash pits, and the fire room floor in front of the furnace should be swept clean. This will prevent the accumulation of wet ashes and leave a clean place for the next round of coal.

When hoisting ashes under forced draft in a closed fire room, some care must be taken to keep the proper door of the tube or ventilator, through which the bucket is hoisted or lowered, closed to prevent the escape of air. By using the bell and speaking tube fitted for communication between the fire room and the deck, this can be done easily, and also much unnecessary noise and delay avoided.

On several naval vessels the ash-hoisting engine and the necessary gear and buckets are replaced by *ash ejectors,* like See's and Davidson's.

Priming Furnaces.—This consists in spreading a thin layer of lump coal over the entire grate, adding one or two shovelsful of picked coal near the furnace door. If there is no fire in any other boiler, the priming charge in front must be laid with wood. The furnaces of empty boilers must never be primed (see Navy Regulations in the Appendix).

Starting Fires.—To start fires, a shovelful of glowing coal from a steaming boiler is put against the front of the priming charge. When the fire must be started from wood, the latter is lighted by means of oily waste.

As the coal burns in front, the rest of the coal is heated slowly by the flame passing to the combustion chamber. During this time the ash pit doors are kept on and the furnace doors are partially open. When the pile near the door has been fully ignited, it is pushed back or spread evenly over the coal on the rest of the grate, and a small amount of fresh coal added in front.

As steam must not be raised in shell boilers, from cold water, in less than six hours, when circumstances will permit (Reguls.), the process of spreading fires is delayed as long as possible, and the draft retarded by keeping the ash pit doors on. The connection doors of shell boilers must, however, neither in starting fires nor at any other time, be used as dampers (Reguls.).

Smoke and Flame.—Smoke, properly speaking, is the vapor and gas coming from burning coal, colored by minute particles of unconsumed carbon. Much of this carbon is deposited as *soot* along its path to the atmosphere. To prevent the formation of smoke, a sufficiently high temperature to ignite the gases and a sufficient supply of air above the grate are necessary. The temperature in a furnace of a marine boiler under steam is generally high enough, unless the fire has been choked with too much fresh coal. But the proper supply of air above the fuel is not always provided, nor attention and care given to its regulation.

With careful and intelligent firing and the air supply efficiently regulated for the two stages of combustion, smoke prevention is almost assured. It should be noted, however, that a greater loss occurs with an excessive air supply and no smoke, than that due to the heat in the form of unconsumed carbon and the heat carried off in the hot gases. This will readily be understood if we remember the enormous volume of air required for the complete combustion of one ton of coal. The absence of smoke does not necessarily mean complete combustion, for carbon monoxide, the result of incomplete combustion, is invisible.

When this carbon monoxide reaches the atmosphere at the top of the smoke pipe, it generally bursts into flame. When flaming occurs under ordinary draft, the ventilators should be trimmed, blowers run a little faster, and the fires allowed to burn down a little.

With strong forced draft, even with good firing, it is not always possible to prevent flames showing at the top of the short smoke pipes generally fitted on torpedo boats, destroyers, and many gun-

boats, and where tubulous boilers are used. When, for military reasons, speed is to be sacrificed to absence of flame, and the air supply and thickness of fire have been regulated and found insufficient, a further help may be given by opening the furnace door slightly.

It will be shown later on how, by an analysis of the smoke or gases of combustion, a practical test can be applied as to the degree of completeness of the combustion.

Mechanical Stokers.—Some of the unavoidable disadvantages of firing by hand, as described above, are minimized or overcome entirely, and better economy of fuel obtained on shore by the use of efficient mechanical stokers. Some have been tried at sea on merchant steamers, but have not given satisfaction in heavy seas. While they are in working order, they give a gradual and continuous supply of and progressive motion to the coal which is most desirable. The coal enters either at or below the furnace door, through a hopper which is kept full, cokes, keeps up heat to consume the gases of the succeeding coal, and burns while it is made to pass either to the back end or to the top of the grate. It then is dropped as ash into the ash pit, or cleaned out through the furnace door. There is no cooling of fires due to the frequent opening of furnace doors; no irregular quantities of coal are thrown on the fire; little or no cleaning of fires; and only one supply of air to regulate, that below the bars in the "overfeed" class, or above and at the sides in the "underfeed" class.

But, apart from the serious mechanical defect that the more or less numerous moving and jointed parts are subjected to the intense heat of the furnace and become warped or deranged, the rate of feed cannot be varied sufficiently to meet the requirements of naval use.

At the present time, no mechanical stoker has given perfect satisfaction on board sea-going ships, although a type of underfeed stoker is in use on several steamers running on the lakes, and for naval purposes hand firing it still the best. With proper training for the men, before they are sent on board ships as firemen, many disadvantages of hand firing will disappear and some advantages will be gained. Poor firemen can cause much more loss in that valuable necessity of a naval vessel—coal—than the gain made by all the improvements in engines and boilers.

Grates and Grate Bars.—The greatest length and width of the

grate have been fixed in the design of the boiler and cannot be increased on board ship. The length of the grate may, however, be shortened, when steaming under an allowance of coal or in port, to suit the kind of coal used and the conditions of draft. Often the allowed supply of coal may not be sufficient to carry a fire heavy enough to cover the whole grate properly, thus causing a loss by admission of air through uncovered bars. By covering a

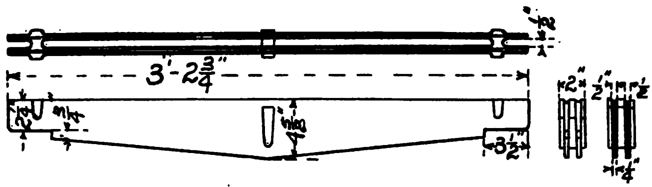


FIG. 2.

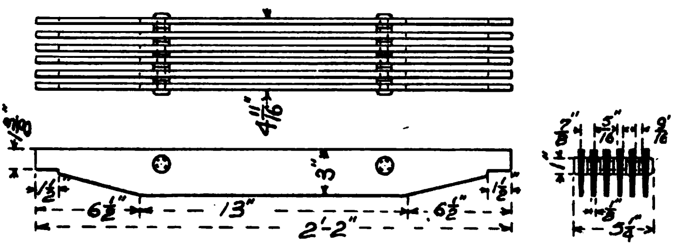


FIG. 3.

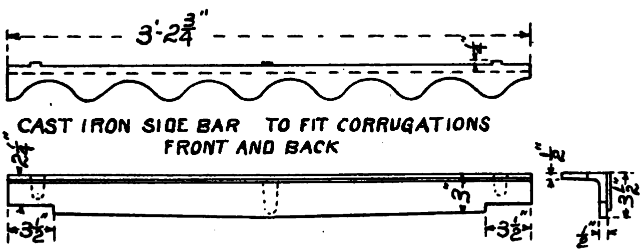


FIG. 4.

part of the grate at the back with bricks or ashes, economy will result. Ashes are better than bricks, for they can be removed more easily and quickly. It may be stated as a general proposition, that with the low furnaces of shell boilers, say longer than 6 feet 6 inches, material economy will follow a reduction of the grate surface and the use of mild forced draft for ordinary cruising.

Grate bars are made of cast iron, steel, and wrought iron. The cast bars are made single and double; when made of steel or

wrought iron and very thin, several bars are generally riveted together to give greater rigidity. The wing bars in shell boilers are cast to suit the corrugations or ribs of the furnace on each side, and should fit close to the furnace side in order to prevent too high a temperature along the plate. Fig. 2 shows the standard cast iron grate bar, and Fig. 3 the usual wrought iron grate bar, put up in bundles of five. Fig. 4 shows a cast iron grate bar used at the sides of corrugated furnaces. Frequently one end of the grate bar is made with a hook at one end, which fits into a groove in the supporting dead plate or bearer bar.

The grate consists of two or three lengths of bars, all, except the wing bars, being interchangeable. The ends of the bars rest on the dead plate, bridge wall, and one or two intermediate bearers. These bearers are either heavy, single or double bars, or square bars which are supported by lugs riveted to the sides of the cylindrical furnace, or by standards in tubulous boilers. Space is left at the ends of the bars for expansion, the usual allowance being 1 inch in 24 inches.

Air Space.—The total opening for air between the bars is fixed at about one-third of the whole grate surface by the designer. For economical combustion, the air space should vary with the kind of coal and the draft. For instance, when burning anthracite and semi-anthracite coal, like some Welsh coals, under natural draft, the air space is generally not more than one-half inch with the usual cast iron bars, and with thin bars it should be less; for bituminous coals, at least one-half inch should be allowed, and, if the coal cokes, three-fourths inch. Under forced draft, these spaces should be reduced, being in some cases as little as one-sixteenth inch.

As these variations cannot be carried out in practice, the air space is, of course, designed for average conditions, and the only change that can be made on board ship, when bars with small spaces are provided, is an increase within small limits. By spacing the bars a little farther apart a gain may result, but care must be taken not to make this too much, as the chances of warping, especially with thin single bars are increased, and loss of fine coal may also result. Ordinarily, the bars should be put in close together.

Cooling of Bars.—The bars are tapered from the top to the bottom, to permit a ready access of air and facilitate the fall of ashes between the bars. Our cast iron bars have a groove on top; ashes accumulating in this groove protect the top from intense

heat. The bars are made deep beyond the supports, not only for strength, but also for the purpose of cooling them. The heat received by the top of the bar is conducted through the latter, and, by heating the film of air on each side, prevents an undue increase of temperature of the bar. To prevent useless heating of the bars from below, as well as a reduction in the draft area, the ash pits should be kept clear of ashes. Trays filled with water have been tried in the ash pits of shell boilers, but the danger from corrosion caused by the salt water is greater than any advantage of its cooling effect on the bars. With tubulous boilers under strong forced draft, the ash pans must always contain water.

Burning of Bars.—In spite of all precautions, grate bars will deteriorate at the top, become warped, or will burn out, so that one or more bars will drop into the ash pit. When the latter happens, the draft in that furnace should be checked, the fire pushed away from the hole left by the dropped bar, and a new bar put in. By tying the new grate bar to a slice bar with marline, it can easily be put in place. The fire is then leveled, the damper opened, and the hot ashes hauled out.

With poor coal, mixed with sand, or containing much slag, the bars will suffer most.

To prevent the burning of bars, when heavy banked fires are kept in an emergency, the ash pit doors must not be put in place (Reguls.).

When through steaming, the grate and bearer bars should be removed from the furnaces, and the grooves in dead plate and bridge wall, and the supports for bearer bars cleaned. Badly burned or warped bars should not be put back. Such bars as are still serviceable should be put in the front part of the grate, care being taken to keep the surface as uniform as possible. If high bars are put alongside of deeply burned ones, they will be burned out more rapidly than if the surface were uniform. New bars should be put in the back of the grate.

Bridge Wall.—In shell boilers, the bridge wall not only limits the extent of the fire, but, by reducing the opening at the back end of the furnace, increases the speed of the gases and thus produces a more complete mixture in the combustion chamber. In tubulous boilers, the brick work at the back simply forms a non-conducting wall to retain the fire.

The opening above the bridge wall is limited by design, but, as the brick work of the bridge does not last very long in service,

careful observation of the effect of increased or decreased opening with different coals may lead to economy in combustion. The bridge wall B, Plate II, shows the latest form adopted for shell boilers, and the continuation of the brick work into and up the back of the combustion chamber. In the older types, the space in the combustion chamber, back of the bridge wall, was not closed.

When through steaming, the brick work, which consists of ordinary fire bricks laid with a thin layer of fire clay on the cast iron frame, must be overhauled. The frame is secured to the furnace and combustion chamber, so that it can be removed, if necessary.

Combustion Chamber.—This chamber is provided in shell boilers to allow the gases to combine, and is made large enough for their combustion as well as for their expansion. Where there are four furnaces in one end of a boiler, there are usually two combustion chambers; where there are three furnaces, the tendency now is to have only one chamber for the three. In this way the combustion chamber is increased in size, without disadvantage, and the full benefit of good firing, as laid down above, is obtained. Sometimes separate combustion chambers are built for each furnace, a more costly and less efficient arrangement. It should be carefully noted that the above arrangement of combustion chambers refers to the furnaces of one end of a boiler only. The dangerous practice of combining these chambers of furnaces at *opposite* ends of a double-ended boiler is obsolete in foreign navies, and has, fortunately, always been avoided in our navy.

In tubulous boilers there is no combustion chamber, properly speaking, although the tendency is to overcome this defect by increasing the space above the fire, and, by bricking, tube walls, or baffle plates, to force the gases into the highest part of this space and thence among the tubes, instead of allowing them to enter among the nearest tubes. Unless this is done and a series of baffle plates is fitted among the tubes, the gases pass so rapidly through the boiler limits that they are only partially consumed and much of their heat is wasted. The latter loss may be decreased by putting in more tubes, but these must not reduce the space above the fire necessary for combustion. In the newer Belleville boilers (see Fig. 121), a combustion chamber, to which air is supplied, is provided between the generating tubes and an additional nest of tubes, called the economizer. The economizer is used as a feed heater.

When through steaming, the combustion chamber of shell boilers must be thoroughly cleaned with brushes of the accumulated soot.

Tubes.—After the gases leave the tubes in a boiler they have usually passed the last heating surface, and, after that, whatever heat remains in the gases is lost, so far as useful heating effect is concerned. There is some heating of the front tube sheet of shell boilers, but this is neglected in computing the heating surface. In return-tube shell boilers, where the tubes are over the furnaces, the change in direction and consequent slight delay of the gases are rather advantageous for combustion. As the opening through or between the tubes is a certain designed area, and as soot is a bad conductor of heat, it is necessary that the tubes be kept clear of soot and cinders. This can be done under way, as previously explained.

Uptake and Smoke Pipe.—From the tubes the gases pass into the uptake, either directly, as in most tubulous boilers, or through the connection and then into the uptake, as in shell boilers. The uptake serves as a conduit between the tubes of one or more boilers and the smoke pipe common to several groups of boilers. The uptakes for each boiler or group of boilers are generally independent up to the protective deck, in order to prevent the mixing of the gases from adjoining boilers or groups of boilers before the gases have passed well beyond the boilers.

After long steaming with bituminous coal, the uptakes should be cleaned of soot and cinders. The interior of the smoke pipe should also be examined, and, if there is much soot, it should be cleaned.

CHAPTER III.

HEATING VALUE OF FUELS AND UTILIZATION OF HEAT.

The heating or calorific value of fuels was, until recently, obtained only by taking the constituent combustible elements of a unit weight as found by chemical analysis, and multiplying the proportionate weight of each by a factor which had been found by experiment. The sum gave the total theoretical heat evolved by the combustion of the fuel, the unit of weight being one pound. This method is not very reliable, and gives results which are usually too large, as it is based on the assumption that the elements exist in the fuel in an uncombined state. It has been shown under "Combustion" that compound gases are first evolved, that these hydrocarbons change their form as further heat is applied, and that a still higher degree of heat is necessary to separate them into the constituent carbon and hydrogen. Although the quantity of heat absorbed in separating the elements is unknown, its omission makes the above method inexact.

A more accurate method, and one which can be carried out on board, is by means of a *fuel calorimeter*. This apparatus and its use will be explained further on.

As the method of chemical analysis is still used and gives fairly approximate results, it is well to understand its application.

From the latest experimental researches, the heat evolved from one pound of combustible is found to be as follows:

Hydrogen	62,000	thermal	units.
Carbon, incomplete combustion, to CO	4,400	"	"
Carbon, complete combustion, to CO_2	14,600	"	"
Sulphur	4,000	"	"
Coal, average composition	14,162	"	"

We have then Dulong's formula for the total heat produced by the combustion of fuel, using the chemical symbols of the elements, and adopting the new constants,

$$h = 14{,}600\ C + 62{,}000\left(H - \frac{O}{8}\right) + 4{,}000\ S$$

or

$$h = 14{,}600\left\{C + 4.25\left(H - \frac{O}{8}\right)\right\}$$

For all practical purposes the heating power of the sulphur may be omitted.

From the above table it will be seen that, when the combustion of carbon is incomplete, more than two-thirds of the theoretical quantity of the heat of complete combustion is lost.

Evaporative Power of the Fuel.—As the heat of the fuel burned in the grate is to be utilized in producing steam from the water in the boiler, a measure has been adopted which is called the *evaporative power of the fuel*, and designated by E. It has been found by experiment that the heat required to convert one pound of water at a temperature of 212° F. into steam of the same temperature is equal to 965.8 thermal units. The total heat of combustion, h, divided by 965.8, will, therefore, give the evaporative power, E, of the fuel; or, in other words, $h \div 965.8 = E =$ number of pounds of water that each pound of the fuel is capable, theoretically, of converting into steam "from and at 212° F." If the method by chemical analysis has been used,

$$E = \frac{h}{965.8} = 15.12 \left\{ C + 4.25\left(H - \frac{O}{8}\right)\right\}.$$

If the total heat of combustion has been found by a calorimeter, its value, naturally, replaces *h* in the second member of the above equation.

If these equations are applied to the average steaming coal noted under "Combustion," the composition of which is 80% C, 5 H, 8 O, and 7 sulphur, moisture, ash, etc., the total available heat in one pound is found to be

$$h = 14,600 \left\{ .80 + 4.25\left(.05 - \frac{.08}{8}\right)\right\} = 14,162 \text{ heat units,}$$

and $E = \dfrac{14,162}{965.8} = 14.66$ pounds of water, which ought, theoretically, to be evaporated by one pound of this coal. In practice, the best results obtained in marine boilers, under the most favorable conditions, rarely reach an evaporation of 11 pounds, and, in general, good practice ranges from 7 to 10, with an average of 9 pounds of water per pound of coal, from and at 212° F. Even with shore boilers under the best conditions, an evaporation of 12 pounds is not often exceeded, and lower figures are the rule.

Loss in Heat.—The chief causes of this great difference, some of which is unavoidable, are:

1. High temperature of furnace gases which escape, as waste, at the smoke pipe.

2. Imperfect firing, resulting
   (a) In incomplete combustion.
   (b) In loss of unburned coal through the grate into the ash pit.
3. External radiation and conduction.

1. *High Temperature of Furnace Gases Escaping at Smoke Pipe.*—This causes the principal loss, most of which is unavoidable with natural draft, as the latter depends upon the difference in the density of the hot gases in the smoke pipe and of the external air. This difference in density depends on the difference in the absolute temperatures of the gases and air. The strongest draft is produced by the pipe when the greastest possible weight of gases is discharged from it per second, and this occurs when the absolute temperature of the gases at the base of the pipe is from 2 to $2\frac{1}{12}$ (Weissbach or Rankine), times that of the external air. Assuming 70° F. as the ordinary temperature of the air, and averaging the results of the two methods, the most effective temperature of the gases is found to be 623° F., or about the temperature of melting lead (617° F.). If the temperature is increased above this point, the velocity of the gases in the pipe is increased, but their density is decreased in a greater ratio; hence, the *weight* of gases discharged, or, in other words, the draft, would be decreased.

This temperature may be decreased when accelerated draft is used, as this has the same effect as lengthening the smoke pipe.

(*a*) *Temperature of the Fire or Combustion.*—By this is meant the temperature of the products of combustion and of the air with which they have been mixed, at the instant that combustion is complete and before heat is abstracted. The difference between the *temperature* and the *total heat* of combustion must be noted here. The temperature depends on the weight and specific heat of the products of combustion, or, in other words, on how much heat is absorbed for complete combustion from the *heat of combustion* of the several combustible elements. Thus, we have seen that the total heat of combustion of carbon is 14,600 heat units. One pound of carbon burned completely in undiluted air gives 3.66 pounds of carbonic acid and 8.94 pounds of nitrogen. The specific heats of carbonic acid and nitrogen being .216 and .244, respectively, the *quantity* of heat required to raise the 12.6 pounds of gases one degree F. will be $3.66 \times .216 + 8.94 \times .244 = 2.972$ units. Then, $14{,}600 \div 2.972 = 4913°$ F. will be the *rise in* temperature

of combustion; or adding the temperature of the air, say, 70°, the temperature of combustion will be 4983°, theoretically.

When coal of the average composition given above, with a calorific value of 14,162 units, is burned under natural draft, or when the surplus of air is equal to that required theoretically, the total weight of the products of combustion per pound of coal is about 22.5 pounds, with a mean specific heat of .242. From this, we get 2600° F., about, for the rise in temperature of combustion. As the most effective temperature of the escaping gases under natural draft should be 623 F., the loss from this source is about 25% under these conditions.

With moderate artificial draft, the weight of gases will be less, and consequently the rise in temperature higher, and the temperature of the escaping gases will be lower. The loss may then be reduced to about 15%. When the combustion is forced, the loss will increase, and be hardly ever less than 25%, and with more violent forcing, very much above this.

The average heat loss from escaping gases may be taken as from 15 to 25% of the heating value of the coal, under most favorable conditions of draft. It should not be forgotten that we have been using the hypothetical temperature of the fire, to obtain which we have assumed complete combustion and no abstraction of heat. But, in practice the combustion is not instantaneous nor completed in the furnace, and heat is continuously abstracted from the gases by the heating surfaces and by radiation. The temperature of the fire is, therefore, in practice, much lower than 2600° F.

During a test of a Babcock and Wilcox boiler at the Massachusetts Institute of Technology (Peabody and Miller), a temperature of about 1100° F. was found immediately above the fire, with a smoke pipe temperature of 400° F.

The following approximate temperatures were found during a test of one of the Babcock and Wilcox boilers for the "Cincinnati." The uptake temperature was obtained by a pyrometer, the others, by means of metals of known melting points inserted between the tubes. The boiler was fitted with baffle plates as shown in Plate IV, dividing the tubes into three sections.

For rates of combustion ranging from 20 to 50 pounds of coal per square foot of grate surface, the temperature of the back section ranged from 840° F. at the top, to 1160°F. at about the middle; was about 780° F. in the middle of the center section; ranged from

625° F. to 650° F. at the top of the front section; and was from 546° F. to 654° F. in the uptake. When the combustion was increased to 59.2 pounds, the temperature was 1160° F. at about the middle of the center section, and about 840° F. at about the middle of the front section, and in the uptake about 820°F.

In the test of a Yarrow boiler on shore, the temperature above the fire varied from 1396° to 2282° F.

The following results of experiments made on a naval return-tube shell boiler, worked at the dock yard at Devenport, England, are given by the present engineer-in-chief of the British Navy, Sir A. J. Durston, in a series of papers.

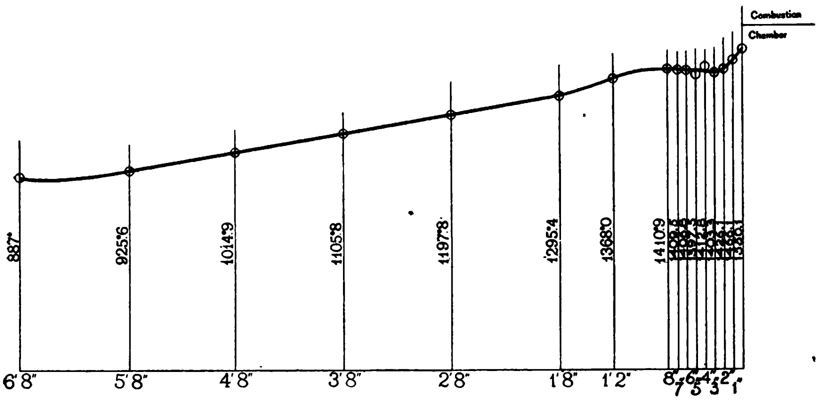


FIG. 5.

The boiler had two furnaces and 166 2¾-inch tubes, 6 feet 8 inches long, from outside of tube plates, and was burning coal at the rate of about 17 pounds per square foot of grate, with smoke pipe draft only. The temperatures were taken by a Le Chatelier thermoelectric pyrometer. The mean results of eight tests showed that the temperature in the combustion chamber was 1644° F.; just inside the tubes, 1550° F., decreasing to 887° at the tube end, and in the front connection to 782° F. The temperature was taken for each foot in the length of the tubes until near the combustion chamber, where it was taken every inch.

Fig. 5 shows the results graphically, the left hand end being the front connection end.

With severe forcing, as in torpedo-boats and destroyers, the smoke pipe temperature is much higher, 1444° F. having been recorded. (Sennett and Oram.)

Various arrangements are in use, (besides the baffle plates among the tubes of tubulous boilers), to decrease the temperature of the escaping gases and the consequent waste. These take the form of feed water heaters placed in the uptake, as in the economizer of the Belleville and earlier type of Babcock and Wilcox boiler, or, of air heaters, as in Howden's forced draft system, and in some of the Babcock and Wilcox boilers. By increasing the heating surface of the boiler proper, the waste is also reduced. The Babcock and Wilcox Company found that the cost of upkeep in a marine boiler economizer, due to the inaccessible position and essential piping, valves, etc., was greater than the advantages derived from its use, and they, therefore, abandoned the economizer in their later types and added its equivalent heating surface to that of the boiler proper.

By the use of feed water heaters in the uptake, the temperature of the gases may be reduced, under most favorable conditions, to about 450° F.

Another arrangement, used formerly with low steam pressures, was the *superheater*. This consisted of a nest of tubes in the uptake into which the steam from the boiler was led. By abstracting heat from the gases, the temperature of the steam was raised and economy resulted. But their economic advantages were outweighed by the practical difficulties of their management and preservation, and they are now rarely used at sea.

2. *Imperfect Firing.*—The loss due to (a) incomplete combustion resulting from poor firing and improper air supply may be very great, reaching from 15 to 25%, but, with good firing and with sufficient air supply and regulation, it may be reduced to from nothing to 4%. Under most favorable conditions, the average loss from this source will be about 1%.

The loss due to (b) unburned coal falling into the ashpit and wasted with the ashes may under unfavorable conditions amount to 8%. With careful firing, so that there will always be a thick enough bed of incandescent fuel to retain the small coal or the pieces that may break off during the heating of the new coal, and with as little disturbance of the fire as possible, together with the reburning of the ashes, this loss may be reduced to from nothing to 2%. The total average loss due to imperfect firing, under most favorable conditions, may then be taken as about 2%.

3. *External Radiation and Conduction.*—The loss from this source, as it cannot be measured, is found by subtracting from the

heating value of the fuel the heat utilized in evaporating the water and that lost at the smoke pipe and by imperfect firing. This remainder also includes all the smaller losses of heat due to various causes, which are not separately enumerated, and may amount to 10 or 15%.

With well-lagged boilers, and furnace fronts, furnace doors and connections fitted with good baffle plates as are our latest boilers, the loss from this source should not average over 7%. It is probably greater in tubulous than in shell boilers.

Efficiency of the Boiler.—This efficiency, also called the evaporative efficiency of the boiler, is measured by the proportionate quantity of heat taken from the available supply in the fuel and applied to the conversion of the water into steam, and is expressed as a percentage of the total heat value of the fuel. It has been shown that this efficiency depends greatly on the care and intelligence with which the fuel and air are supplied and regulated. Besides these factors, the design of the boiler, and the amount, arrangement and cleanliness of the heating surface are very important ones. Much depends on the management of the boilers on board ship in keeping the heating surfaces clean. Leaks from the boiler are also important sources of loss.

In a naval boiler of the best design, with very careful firing and a moderate rate of combustion of fuel (say 18 to 20 lbs. of coal per square foot of grate per hour), the losses under the most favorable sea-going conditions, may be tabulated from the above as follows:

Heat of fuel taken up by feed water, or, utilized in evaporating the water, per cent	68
1. Loss by escaping gases at smoke pipe, per cent	23
2. Loss by imperfect firing, per cent	2
3. Loss by radiation and other causes, per cent	7
	100

From the above it is seen that the efficiency is 68%. This may fall under unfavorable conditions and poorly designed boilers to less than 50%, and rise, in exceptional cases, to nearly 75%. As the loss under 2 ranges from 2 to 33%, and depends chiefly on the quality of the firemen, and is, practically, the only variable in a given boiler installation on board ship, the great importance of having intelligent and well-trained firemen is apparent.

CHAPTER IV.

FUELS.

Coal.—Coal is divided into classes, depending upon the amount of fixed carbon contained. Besides the available combustible elements of carbon and hydrogen, coal contains oxygen, sulphur and the incombustible *ash* and *moisture*, the latter absorbed from the atmosphere. The oxygen in the coal, as we have seen, detracts from its heating value. Sulphur, which is generally visible in the form of pyrites, should not exist in good coal, as its presence is a source of danger from spontaneous combustion.

When inspecting coal for purchase at foreign ports, the following general requirements should be carried out. If time permits, a sample (from ½ to 1 ton in weight) should be burned on board before accepting the coal. Good coal should contain about an equal proportion of lumps and slack. It should not be wet, as the moisture it has absorbed is a dead loss, besides being considered a source of danger from spontaneous combustion. It should not be weather-worn or rusty in appearance. It should contain no slate, stone, sand, nor other impurities. It should be bright black, and when broken, the dust should be bright and the fracture clear. If the color of the coal is brown, brownish or gray, its heating value will be less; similarly, if the fracture is dull or lustreless and the dust earthy, the value of the coal will be less on account of the increased proportion of refuse. When burning, the coal should not cake too much.

The following classification is frequently adopted and also shows the age of formation of the coal, lignite or brown coal being the latest. The volatile matter decreases and the fixed carbon increases with the age of the formation.

1. Brown coal or lignite. Very soft and very much smoke. Generally much moisture and mineral matter. Generally unsuitable for naval use. Less than 50% carbon and more than 50% volatile matter.

2. Bituminous. Soft. Much smoke and generally long flame.

Very easily ignited. Non-caking kind suitable for marine use. The Washington State, Alabama and Pittsburg are American bituminous, and Comox, Wellington and Nanaimo are samples of British Columbia bituminous; 50 to 75% carbon and 25 to 50% volatile matter.

3. Semi-bituminous. Moderately hard; bright fracture. Little smoke and short flame. Easily ignited. Of these the Pocahontas, George's Creek and Clearfield are the best American examples; Cardiff or Welsh are the best foreign varieties; 75 to 85% carbon and 15 to 25% volatile matter.

4. Semi-anthracite. Approaching anthracite. Short flame. Very little smoke. Will soil the hand when rubbed over a newly broken surface. Ignites readily; 85 to 90% carbon and 10 to 15% volatile matter.

5. Anthracite. Hard and lustrous. Gives intense heat, no smoke, and little flame. Glassy fracture. Hard to ignite. Does not soil the hand; 90 to 100% carbon and 10 to 0% volatile matter.

The difference between bituminous and semi-bituminous, and semi-bituminous and semi-anthracite is often rather indefinite, but the above points may be used to separate them.

The "proximate analysis" of the coal, by which the proportion of fixed carbon and volatile matter in the dry combustible, or, in the dry coal free from ash is determined, serves as a guide for the best manner of burning the coal. The distillation of the gases takes place very quickly with the bituminous coals, and the rate decreases with the semi-bituminous and anthracite coals.

Table I gives the ultimate chemical analysis, the proximate analysis, the heating value of the fuel per pound of dry combustible, and the space in cubic feet occupied by one ton in the bunkers. The data have been compiled from various sources mentioned at the beginning of this book. The ash in the table must not be confused with the greater quantity of ashes or refuse from the ordinary firing, as it is the residue from a chemical analysis. The "space occupied by 1 ton" in the bunkers is as accurate as can be given under present circumstances. The Bureau of Steam Engineering adopts 43.5 cubic feet per ton as an average for all kinds of coal.

TABLE I.

CHEMICAL COMPOSITION OF VARIOUS STEAMING COALS AND LIQUID FUELS, THEIR HEATING VALUES, AND VOLUME OCCUPIED BY ONE TON.

Name of Fuel and Country from which obtained.	Ultimate Analysis.						Proximate Analysis.				Heating value of one pound of dry fuel in B. T. U.	Number of cubic feet occupied by one ton of 2240 pounds of fuel.
	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.	Fixed Carbon.	Volatile Matter.	Ash.	Moisture.		
Anthr. and Semi-Anthr.												
Pennsylvania, av.........Am.	....	....	....	....	....	....	88.5	4.0	6.3	1.2	13,100	42.4
Lehigh, Pa.............. "	85.7	2.8	2.9	.8	.5	7.3	86.5	4.8	7.2	2.0	....	....
Drifton, Pa.............. "	87.7	2.6	2.3	1.0	.4	6.0	89.1	3.6	5.9	1.4	13,722	....
Nixon's Navigation ..Wales.	87.7	4.0	2.5		5.8		....	....	....	....	15,010	....
Powell's Duffryn... "	88.3	4.6	.6	1.4	1.8	3.3	....	....	....	...	16,108	....
Isère ....France.	90.0	1.5	1.5		7.0		....	...	....	....	13,782	40.0
Semi-Bituminous.												
Pocahontas, W. Va......Am.	83.5	4.8	4.2	1.3	.7	5.5	77.8	17.1	5.1	.5	14,578	44.1 av. Am.
New River, W. Va....... "	83.6	4.7	4.5	1.6	.7	4.9	72.7	21.7	4.8	.8	14,488	
George's Creek, Md..... "	81.0	4.9	4.6	2.2	.7	6.6	74.8	18.5	6.6	.6	13,987	
Clearfield, Pa........... "	80.2	5.1	4.7	1.4	.9	7.7	73.2	18.8	7.6	.4	....	
Cardiff, av ....Wales.	83.8	4.8	4.1	1.0	1.4	4.9	80.	17.	8.	....	...	42.7 ?
Newcastle .... Engl.	82.4	5.5	6.3	1.6	1.3	2.9	....	....	....	....	14,820	45.3
Bituminous.												
Pittsburg Steamg.......Am.	76.5	5.2	8.1	1.4	1.2	7.6	59.1	32.0	7.5	1.4	13.280	....
Pratt seam, Ala.... ..... "	....	....	....	....	...	....	63.8	31.5	3.5	1.2	14,580	....
Washington State, av... "	....	....	....	....	....	....	57.7	32.8	8.3	1.2	....	45.5
Br. Columbia, av.............	..	....	....	....	....	....	56.5	33.7	8.1	1.3	..	
Scotch, av	78.5	5.6	9.7	1.0	1.1	4.1	....	....	....	...	12,870	45.0
Miike .... Japan.	75.0	5.8	?	1.1	3.2	12.0?	....	....	....	....	....	45.6
Chilian, av.........	63.6	5.4	14.8	.8	2.5	12.9	....	....	....	....	11,030	46.5 ?
Patent Fuel.												
British, av....................	83.4	5.0	2.8	1.1	1.3	6.4	....	....	....	....	15,000	34.4
Warlich's..............Engl.	90.0	5.6	....	....	1.6	2.8?	....	...	....	....	16.495	....
French, av..................	....	...	....	....	....	3.3	....	....	....	....	15,000	34.5
Liquid Fuel.							Sp. Gr.	Flash	Fire			
Pennsylvania, Kerosene....	85.0	13.5	1.5	....	...	....	.784	120°	150°	....	20,156	
Pratt's fuel oil, Pa..........	....	....	...	....	....	....	.852	200	268	....	19.980	34–36
Eagle fuel oil, Pa............	....	....	....	....	....	....	.849	249	296	....	19,742	
Beaumont, Tex., distilled...	83.8	12.9	3.8	....	.5	....	.926	216	240	....	19,480	
Kern River, Cal., distilled...	84.4	11.0	3.4	.6	.6	....	.962	228	258	...	18,806	
Astatki, Baku,* Russ........	85.0	13.7	1.3	....	....	....	.940	....	....	2.0	18,560	35.0 av.
Borneo, crude..............	83.4	10.3	6.3	(incl.	imp	ur'es)	.960	....	....	12.0	18,000	
Burma, refuse*..............	86.0	12.4	1.6	....	....	....	....	....	....	....	18,860	

* After sulphur and other impurities have been removed.

Patent Fuel.—In order to utilize the small coal or slack at the mines, various plans have been tried, of which the patent fuel, or briquette, is the only one useful for naval purposes. The

numerous kinds of this fuel consist of fine coal and some binding material, the quality of the coal used being the chief factor in that of the bricks. In the best kinds, tar or pitch is used as the binding material, and in the inferior ones, lime, clay or cement, these resulting in a much larger percentage of ash. The mixture is baked and the volatile matter driven off, the mass being then compressed in the form of large thick bricks. These are easily handled, stow well, and burn readily with good results. The table shows that 34.4 cubic feet only are occupied by 1 ton of patent fuel, which is a decided gain over the ordinary 43.5 or 45 cubic feet. Its evaporative power is high, good briquettes, used in the French navy, giving an evaporation of 9.6 pounds of water per pound of fuel, and good English and German examples, about 9.2 pounds. Briquettes of Japanese anthracite and bituminous coals are made for and used by the Japanese navy, these giving better results than the bituminous coals from Takasima, Shinbara, Gotoku, or Miike.

Liquid Fuel.—When this kind of fuel can be used generally on board naval vessels instead of coal, the ideal will have been obtained. While it is used now to a comparatively limited extent only, either alone or in combination with coal, on naval and mercantile vessels, it may not be long before it will be *the* fuel for naval ships.

Nature of Liquid Fuel.—Besides the crude petroleum and petroleum residue or refuse, which are here described as *liquid fuel,* other substances have been tried, among which are (1) crude coal tar, (2) tar and creosote oils, and (3) shale oil. The supply of the first is very limited and cannot, therefore, be considered for general purposes. The second have a limited use in the German navy, under the name of *masut,* but they are worth more for use in the arts than as fuel. The third, which is the heavy oil from Bog Head coal, found somewhat extensively in Scotland, makes a good fuel, being heavier than water and having a high flashing point; but, owing to the demand for other uses (for paraffine and paraffine oil production), it may be neglected as a fuel. It requires about 1 ton of the shale to make 1 barrel of 42 gallons, or about 310 pounds, of petroleum distillate.

After years of experimenting with various forms of petroleum, it seems now to be settled that some one of the residues, left after the different distillations or refinements to which crude

petroleum is subjected, is the only practicable oil. When the crude petroleum is subjected to distillation, it gives off, at first, some highly inflammable vapors, then gasoline, benzine and naphtha; the next stage produces the lighting or lamp oil, kerosene; then, in the next, the lubricating oils, the "mineral oils" of commerce. The residues left after the last two distillations form the *liquid fuel,* in the case of Pennsylvania and Russian oils. With the newer and heavier Texas, California and Borneo oils, only one distillation is, at present, necessary.

Astatki is the Russian name given to the residue of petroleum after the illuminating oils have been distilled off, and amounts to nearly 50% of the total production of the Russian fields. This is the liquid fuel generally used in Europe. It is very viscous and heavy, its specific gravity being about .94, and has a flashing point of over 300° F., while not giving off any vapors under 250° F. It may be exposed with impunity to the explosion of a Hotchkiss shell, its storage and handling, therefore, presenting very little risk (Bertin).

The earlier experiments with liquid fuel in this country were made with the crude Pennsylvania petroleum, which, owing to its low burning point, high cost compared with coal, and limited supply, made it unsuitable and dangerous for use on board. In the later experiments made by the Bureau of Steam Engineering, which began in 1898, and which have not yet been completed, the first oil used was the commercial "fuel" oil, now sold on the Atlantic coast. It is somewhat like lubricating oil, unpurified, and has a specific gravity of about .86, a flash point of about 315° F. and a burning point of about 350° F. Burning waste, when plunged into the oil, was extinguished. There is no doubt, therefore, of its safety for use on board ship. The experiments in 1902 were made with Beaumont, Texas, oil.

Sources of Supply.—The chief sources of crude petroleum now are the Appalachian and Lima-Indiana fields, the product of which is commonly known as "Pennsylvania" oil, and the more recent California and Texas fields in this country; the Baku and Gosni districts in the Caucasus; Galicia in Austria; Roumania; Sumatra and Java; Japan; Burma, and, more recently, Borneo. Of these, Galicia, Roumania and Japan may be neglected as fuel producers, as these countries import petroleum in addition to their own supply. As the residue left from the numerous

distillations of the light "Pennsylvania" oils, is very small, these two fields, although they produce over 90% of the total crude petroleum in this country, would not alone furnish a sufficient supply. Should the hopes for the California and new Texas fields, and the possibilities of Wyoming as a large producer, be realized, the question of supply for our naval purposes may be settled satisfactorily.

The "Pennsylvania" oils are light and can be refined very readily, while those of California, Texas and Wyoming are heavy and are now good for lubricating oils and fuel.

The average distillation or refining of crude Pennsylvania oil (about .82 sp. gr. at 62° F.) is estimated to yield:

11% gasoline, benzine and naphtha.
76% kerosene or illuminating oil.
3% lubricating oil.
10% residuum and loss.

The distillation of the crude oil from the Corsicana, Texas, district (about .82 sp. gr.) gives:

10.8% naphtha, etc.
54.5% kerosene.
34.7% residuum (sp. gr. .905).

The heavier oils from the new Beaumont fields in Texas give a higher percentage of residuum. The specific gravity of the Beaumont crude oil is about .92. It has a flashing point of 142 to 180° F., burns at 180 to 200° F., and contains from 2 to 3% sulphur. In its crude state it would not do for ship fuel; but, by distilling off some of the volatile products, its firing point can be raised to a safe limit, say 250 or 300° F.

Of the foreign sources, the Baku district, which is a greater producer of crude oil than the whole United States (for 1900), furnishes about one-half of its total production in the form of residuum. The crude oil has a specific gravity of about .86, and the astatki, about .94.

The newer Borneo oil is used, generally, in its crude state, although it contains about 12% water. It is almost odorless.

The use of liquid fuel has increased very much in recent years, following the discovery of new fields, so that a limited supply can now be obtained at the oil stations which are established at nearly every important port from the Mediterranean to Yokohama. These stations have a pumping capacity of from 100 to

300 tons of oil per hour, the latter rate being nearly equal to the amount of coal that can be put into roomy bunkers at Port Saïd, Nagasaki and Singapore.

Our Eastern coast, Europe and the Mediterranean will soon be similarly fitted out with stations for Texas oil. San Francisco is already supplied with pumping stations and the California oil is used on steamers, locomotives and in factories.

Evaporative Power and Efficiency.—The average power of liquid fuel, from trials on torpedo boats of various navies, may be taken as not over 1.5 times that of good steaming coal. If its stowing capacity when "dry" (35 cubic feet to the ton), is taken into account, about one-fourth greater than that of coal at 44 cubic feet to the ton, the efficiency of liquid fuel is 1¾ times. Or, in other words, if the steaming radius of a ship is 4000 nautical miles with coal, this would be increased to 7000 nautical miles when using liquid fuel, freed from water, in the same bunker space.

In a paper read before the Institution of Naval Architects in March, 1902, Mr. Flannery says that 36 cubic feet of oil are equal to 67 cubic feet of coal as usually stowed; this gives a final efficiency of 1.86, or a little greater than that given above. This is based on the experience gained in the merchant service, of which an example is given in the case of the S. S. "Murex." This steamer ran from Singapore to the Thames, a distance of 11,800 nautical miles, via the Cape of Good Hope, on an average daily consumption of 16 tons of Borneo oil, using burners with steam atomizers. The average for coal on the same run and for the same power is given at 25 tons.

Burners.—While the number of patented devices for burning liquid fuel is very large, the principal methods may be narrowed down to two, (1) pulverizing or atomizing, and (2) gasifying the oil before it is burned. The object sought is to secure a complete and intimate mixture of air with a constant supply of oil, either in a finely-divided liquid or in a gaseous state, and to maintain the temperature sufficiently high for combustion by the use of more or less brickwork in the furnace, and, often, by previous heating of the air. With all forms of burners, the oil must be heated and filtered. Unless the oil has been "dried" before it is put into the ship, suitable provision must be made to allow the water to settle and then to draw it off.

1. Pulverizing Method. The oil is pumped from the bunkers into a reservoir or settling tank, where it is in some cases heated. From this tank it is allowed to flow by gravity to the burners, or, in the more successful cases, forced to the burners under a constant pressure. At the mouth of the burner the oil is formed into a small jet or spray, either by the pressure only, as in the ordinary atomizer, or by the help of a strong jet of steam or compressed air. The air for combustion is supplied in the ordinary way through the ash pit and other openings, or by the jet of compressed air, or by both means. The jet of steam or compressed air is, generally, concentric with the jet of oil, but in some burners, constructed like the ordinary atomizer, is at an angle. The supply of oil and steam or compressed air can be controlled independently, and, when properly regulated, there will be a clear flame and no smoke under ordinary conditions of draft.

As the jet of pulverized oil and steam or air forms a long flame, brick baffles must be provided to prevent its striking the comparatively cool heating surfaces (only 300 to 400° F.) in the combustion chambers of shell boilers, before the combustion is completed. If the furnace is sufficiently long, no baffles need be fitted, and better results may be expected. Frequently, a layer of bricks or cinders is provided under the jet in order to catch and ignite any oil that may drop from the burner.

Grundell-Tucker Burner.—Fig. 6 shows this burner as fitted to the shell boilers of the S. S. "Mariposa" of the Oceanic Steamship Company, running between San Francisco and Tahiti.

In this arrangement, compressed air, limited to a pressure of 40 pounds per square inch, is used, the oil being forced into the burner at the same pressure as the air. The burner consists of two pipes, the heated oil passing through the inner pipe to the nozzle, where it is thrown out radially through the ring of small holes. The air is heated to the temperature due to the compression, which is usually twenty pounds, and can be further heated to about 360° F. in air heaters in the furnace front. The compressed air surrounds the inner tube and passes axially along this pipe to near the end, where it is given a whirling motion by the small helical grooves in the enlarged part of the oil pipe. The outer ends of these grooves stop just above the ring of oil holes, so that the whirling streams of air meet the radial streams of oil. The latter are thus broken up into fine spray, the drops

of which can be seen before they ignite. The combined spray of air and oil is spread out into a rose shape by the hood and enlarged end on the nozzle of the burner. The oil pipe is adjustable, so that the opening between it and the hood can be regulated to give the best form to the rose-shaped flame.

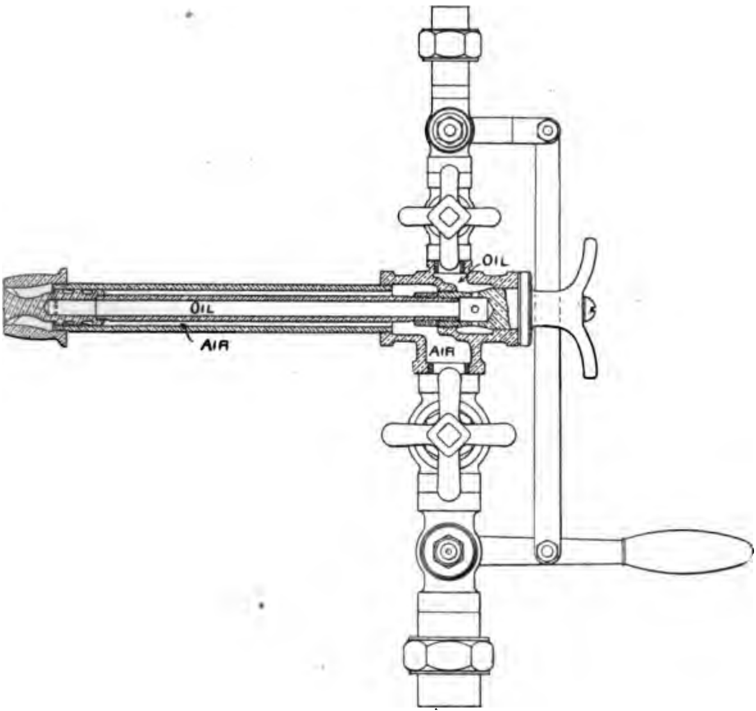


FIG. 6.

The air and oil supply can be regulated independently by the valves in the supply pipes, and can be shut off together, in an emergency, by a lever connected to a plug cock in each pipe. The air supply pipe is also connected to the auxiliary steam pipe line, so that steam can be quickly substituted, if desired. Additional air (cold) for combustion is admitted through the hinged ash pit door, and is directed up across the flame and slightly heated by a curved fire-brick wall built in the ash pit close to the front. When the air and oil valves have been properly regulated,

the flame is steady, white or yellowish-white in color, and fills the furnace, and no smoke is formed.

The oil used on the "Mariposa" is from the Kern River district in California. It should not be heated to more than 150° F. and should be kept at a constant temperature. At the usual temperature of the atmosphere it is dark and thick, like molasses.

There are two burners to each furnace. Owing to the small deposit of soot in the tubes, the round trip of twenty-four days' steaming can be made without sweeping tubes.

Oil City Boiler Works' Burner.—Fig. 7 shows this burner arranged for the use of steam as the pulverizing medium, and as tested at Washington by a naval board. Burners using air, designed by the same firm, were also tested. They are similar in construction, the pipe surrounding the oil pipe being larger.

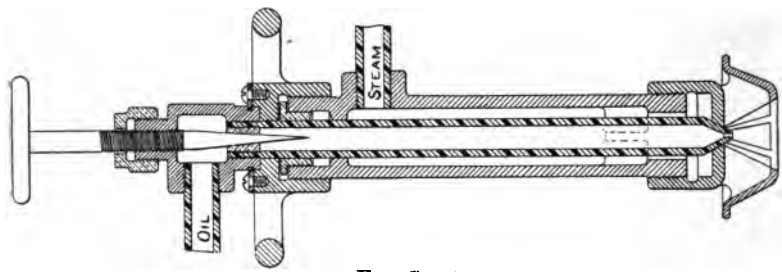


FIG. 7.

The general arrangement is similar to the previous burner, the inner pipe conveying oil under pressure to a small central opening at the nozzle end. Surrounding the oil pipe is a steam pipe, the opening of which at the burner end can be altered by the valve-shaped point of the oil pipe. This regulation is effected by means of the hand wheel. A hood over the end of the burner is so fitted that air is drawn in to mix with the spray of steam and oil, all three being then spread out by the rose-shaped end. The oil supply is regulated by the needle-pointed valve in the front of the oil pipe.

Three tests were made, the oil pressure being 20, 30 and 45 pounds, and the corresponding pressures of the steam used for atomizing being 30, 61.5 and 91 pounds per square inch, the steam in each case being slightly superheated. The quantity of steam used for atomizing was 4, 4.5 and 5 per cent of the total quantity generated.

It was found that when using steam, the noise was less than with air. The evaporative results when using air were better than with steam.

Korting Burner.—In this type, Fig. 8, no atomizing agent is used. The oil is forced out of the nozzle under a constant pressure, which varies in different burners from 20 to 50 lbs. per square inch. The air for combustion is partly drawn in with the

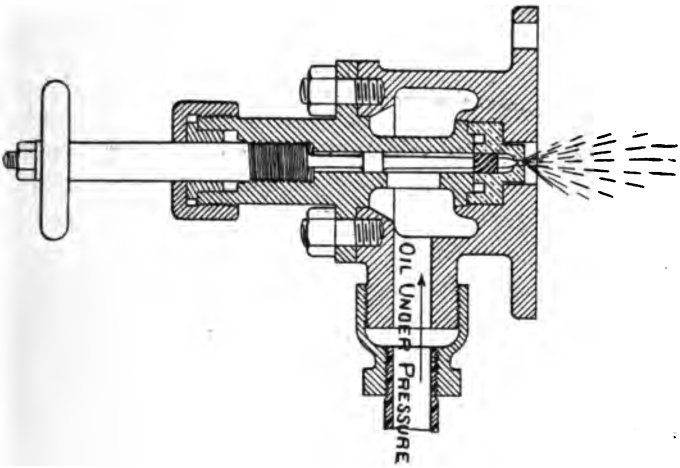


FIG. 8.

stream of small drops, chiefly through the ash pit. No steam is wasted in atomizing the oil, nor is an air compressor required. More unconsumed oil issues from the burner, a metal trough underneath catching this and returning it to the front of the boiler.

The hole through which the oil is forced is about .05 inch in diameter, the opening being regulated by a small pin on the end of the valve stem. To assist in breaking up the oil into spray, the valve stem is fitted with a spirally-grooved collar a short distance from the pin. It is particularly necessary with this burner to provide means for heating the air that is drawn in. A simple arrangement which has worked satisfactorily on several steamers, is to cover the greater part of the grate with rather heavy cast-iron plates, leaving the front end of the grate open.

A light baffle plate, fitted in the ash pit, guides the entering air to the back of the furnace and returns it, between the baffle and the cast-iron plates above, to the opening left in the front of the grate. As the cast-iron plates soon become red hot, the air is heated before it meets the oil. The oil is heated to about 200° F. before entering the burner, and special filters are provided.

2. In the gasifying or retort method, the oil, under pressure, is volatilized in a retort by the heat of a spray burner, the gas being mixed with heated air, either before or after issuing from the nozzle of the retort.

Steam or Compressed Air as Pulverizing Medium.—As the use of steam in the burner entails a heavy waste of fresh water, which must be made up by extra evaporators, compressed air would seem to be preferable. Steam is, however, more generally used, although reliable experiments have not yet been made to determine the relative values of the two mediums. With a light and economical air compressor, by the use of which the steam (or fresh water) is saved and no extra evaporators are required, the consumption of steam may be taken as about one-fourth of that when it is used direct in the burner. Experiments made to determine the quantity of steam used direct show that it averages about .4 or .5 pounds of steam per pound of oil burned, or about 2% of the total steam generated in the boiler.

When steam is used, there is always the risk of extinguishing the flame by the water which may be carried over with the steam from the boiler. When air is used, it must be raised to a high temperature before entering the burner. The flame with air pressure is generally shorter than with steam pressure, giving a more intense heat for a short distance. While the air compressing machinery can be made less in weight than the extra evaporators required with steam, the whole air system will be more complicated than the steam system and much noisier in use. Before lighting a furnace using oil fuel, it should be blown through, preferably with a steam jet. The steam jet should be turned on first and then a torch or starting light put in the furnace before the oil valve is opened. In this way, danger from explosion in the furnace is avoided.

With either medium, the same difficulty exists in starting fires when no steam is on the ship, as a special fire must be made, or a hand air compressor used.

Advantages and Disadvantages of Liquid Fuel.—Advantages.

1. Very high evaporative power, from which it follows that a greater distance can be steamed on the same weight of fuel, or, that less weight of fuel need be carried to steam the same distance.

2. Fewer firemen and coal passers needed, and their work very much lightened and eased, owing to the suppression of the exhausting work of hand firing and trimming of coal. The reduction of men will be greater in the merchant service than in a warship.

3. Reduction in the fire room and bunker spaces. The space now required in each fire room for working the firing tools would be reduced considerably. Although the bunkers for oil require special bulkheads and arrangements, yet, owing to the smaller space occupied by a ton of oil and the utilization of unused spaces, the bunker space would be reduced.

4. Regularity of combustion. No opening of furnace doors for coaling or cleaning and consequent changes in temperature. The life of the boiler is, therefore, increased, and fairly high rates of combustion can be obtained without danger.

5. No cleaning of fires and consequent drop in the steam pressure, the fire being always clean and in good condition. With properly-regulated burners there will be no smoke.

6. No coal dust and ashes. Besides the improved cleanliness and reduced work due to the absence of both, the safety of the ship will be improved, as the bilges, strainers and bilge pumps will not become choked and inoperative, as frequently happens with coal.

7. Better control over production of steam, as fires can be started and stopped much more quickly.

Disadvantages. 1. The greatest obstacle to the general use of any form of petroleum has, heretofore, been its limited supply, when compared with the enormous quantity of coal used by steamers. But, if the output of the new fields in Borneo, Texas, California and the Dutch East Indies is equal to the expecta-

tions, and the hopes of discovery of other and additional fields are realized, the obstacle of supply, or price, may be overcome. As shown above, the introduction of Borneo and Sumatra oil has already made it possible for a few merchant steamers to take on fuel, to a limited extent, at almost every large port between the Mediterranean and the Far East. With the supply, or price, of oil fuel nearly or altogether on an equality with coal, there remain only the following disadvantages, with the present type of machinery.

2. So far as a somewhat limited number of experiments in various navies has shown, the development of the full power of a boiler, especially of the tubulous type, cannot generally be obtained by burning liquid fuel; or, in other words, that liquid fuel cannot be advantageously employed with a heavy forced draft. The experiments made by our navy in 1902, and referred to later, show that the special boiler tried could be forced with oil to the same extent as with coal, but the efficiency was not so high and the formation of smoke could not be prevented. Further experiments may show what changes are necessary in burners and boilers, so that the same power, for a given size or weight of boiler designed to burn coal only, can be obtained by burning an equivalent quantity of liquid fuel.

The trials with oil alone made on merchant steamers, which have shown good results, do not, as it may seem, disprove this. The boilers of these ships are not forced, but are worked at about the power for which they were designed. Whatever gain in fuel economy or power is made is due to the more nearly perfect combustion of the fuel and the continuous use of artificial draft.

The reason for this failure to develop a high power satisfactorily in a boiler not specially designed for the use of oil is evident. When the burner has been regulated to prevent smoke, the combustion is complete, and this is, therefore, all that this one burner can do. This stage of perfect combustion is reached in all methods of burning, when the very small opening, through which the oil mist or the oil gas issue, is open just enough to combine with a proper supply of air. If the opening is made larger, more oil will be forced through, but combustion will not be complete and the apparatus will soon be useless. The only remedy, if more heat is needed, is to install as many additional burners as the boiler will permit.

The ordinary gas burner in a room will furnish an illustration of the limits of the oil burner. When the gas is turned on full, a certain amount of light (or heat) is obtained, which can be increased materially only by lighting additional burners. Within small limits, the one burner can be made to give more light from the same pipe, by putting in a tip with a larger slit, or, by increasing the pressure in the gasometer. In the installation of the liquid fuel burners, the burner will, of course, be put in originally as large as possible, and the pressure will be the greatest permissible, so that an increase must be sought in number and not in size.

3. Additional evaporators to supply the steam used in the burners. Even if further experiments do not show the superiority of compressed air over steam as the pulverizing medium, this disadvantage may be overcome, entirely or in part, at least on large ships, by the advantages mentioned in item 3 above.

4. The great noise and vibration made by the burners, especially when air is used. The former defect would be a grave one in torpedo boats when used at night. On the U. S. T. B. *Talbot,* the noise and vibration due to the air compressors were greater than those due to the main engines.

5. Other but perhaps not insuperable objections are the special arrangement and care of bunkers and other spaces used for stowing the oil. The fluidity of this fuel, which forms one of its great advantages, may, at times, prove to be a dangerous disadvantage. In 1901, the German battleship *Kaiser Friedrich III,* which carried liquid fuel, chiefly creosote, as an emergency fuel in the double bottoms under two of the three boiler compartments, struck a rock, which bent in and broke a number of plates of the outer skin. The oil, as the tanks were quite full, was thus put under a heavy pressure, which forced it through the vent pipe out on the upper deck. This pipe broke in two places in the starboard middle fire room and the oil was soon on fire. Oil also ran into the port after fire room (which had to be abandoned on account of the rapid inrush of water), and thence through leaks in the longitudinal bulkhead into the starboard after fire room. The fires in the boilers in this room were, therefore, put out, as well as in the port middle fire room, where oil entered with the water from the bilge. The port forward boilers were the only ones available, and these could be used only at a reduced pres-

sure, owing to the condensation in the steam pipes which led aft through the flooded compartment. The burning oil in the starboard middle fire room was put out by flooding, and although great damage was caused, happily, no lives were lost. The great heat necessitated the flooding of two ammunition rooms adjacent to the injured boiler compartments, and started the coal in adjacent bunkers to smolder.

Ten of the twelve boilers of the ship and two ammunition rooms were thus put out of commission for the time being, due to the presence of oil. Had there been no oil in the double bottoms, two boilers only would have been put out of use by the grounding, and the ammunition rooms need not have been flooded. The court of inquiry found that the use of the double bottom for carrying water and fuel oil did not prove so disastrous to the safety of the ship as was feared, but, whether this security would remain if the outer skin was punctured by explosive bodies, is another question. They recommended that fuel oil be stowed as far as possible from boilers, that the tanks be never filled entirely and that they be provided with a large air chamber. The vent pipes should be large and double and be as far removed as possible from boilers, and their outlets lead outboard above the water line. Oil pumps should be put in each fire room and not all in one room, and should have a discharge directly overboard.

Use as Emergency Fuel.—While waiting for further developments in the conditions which will make the use of oil fuel alone practicable, several continental navies have installed liquid fuel burners in addition to the grates in furnaces arranged to burn coal. Two or three small burners are fitted, and the spray of liquid fuel is directed over the incandescent coal whenever an increase in boiler power is wanted quickly, as in an emergency. Not only is the heat of combustion of the liquid fuel added, but an increased efficiency in the combustion of the coal is, probably, also obtained. Besides having this emergency fuel at hand for an increase in the power of the boiler, it can also be used to maintain the power of the boiler when the coal fires are badly clinkered and it is not advisable to clean them at the time.

In a recent trial of a torpedo boat for the Dutch government, the speed with coal alone, burning 2800 pounds per hour under two Yarrow tubulous boilers, was 24.5 knots; when the oil burners (Holden's) were started in addition to this, and burning 700 pounds

of Borneo oil per hour, the speed was increased and kept up to 26.5 knots.

Experiments on the "Surly."—Tests have been made on this British torpedo gunboat, fitted with Normand tubulous boilers, and Holden burners, with varying changes in the arrangement of the brickwork, the number and arrangement of burners, and the pressure of steam used in pulverizing. Compressed air was found unsuitable, owing to the size of the compressors required, and steam only is now used, extra evaporators being fitted. When burned in combination with coal, only $\frac{8}{10}$ of the full power of the boiler could be maintained, and when burning oil alone, injected against brickwork baffles, not more than $\frac{3}{10}$ of the power has yet been obtained. (Sennett and Oram.)

An installation of oil burners in combination with coal has been fitted to part of the boilers of the large British cruiser "Arrogant."

Experiments by the Bureau of Steam Engineering.—Tests with various forms of burners have been made on the torpedo boat *Talbot*. Owing to the want of officers to conduct the tests continuously, no positive results, so far as the adoption of any particular burner or oil is concerned, were secured. As stated in the report of the Chief of the Bureau of Steam Engineering for 1900:

"So far, the success with the jet type of burner does not seem to indicate possible satisfaction. The best type of jet or spray burner yet used on the *Talbot* has failed to secure power for a sustained speed of more than three-fourths the full trial speed of the boat, even for half an hour, while the smoke feature is equally as evident as with soft coal, except at a speed as low as ten knots.

"Great convenience attaches itself to the use of oil fuel, especially in these small boats, owing to the instant control obtained thereby over the fires, and the avoidance of handling ashes or cleaning fires while underway. In point of economy and full efficiency, however, it has not yet been demonstrated, either in this country or abroad, that a change from coal is possible at present.

"The first desideratum in this field is to secure full power without smoke, the matter of economy in torpedo boat class being of secondary consideration. By reason of this smoke question, the difficulties are greater than they otherwise would be."

Later and more numerous tests with Beaumont oil and with coal were made on a Hohenstein tubulous boiler, in 1902, at Washington, D. C. From the reports of the Chief of Bureau and the Trial Board, the following points may be gathered:

"The oil should be atomized before ignition, as it is impossible to gasify it completely. That, to secure the best results, it is highly probable that the boiler must be designed for the special purpose of burning liquid fuel. The oil and the air for combustion must be heated.

"It has always been possible to burn some oil and to secure nearly the full thermal efficiency of the combustible, but no one seemed to know how to burn enough oil and yet have it under control. There is, therefore, no record that, previous to two years ago, any boiler ever evaporated the amount of water with oil that was secured under forced draft conditions with coal as the fuel. In other words, the boiler could not be forced with oil to the same extent as with coal. The experiments conducted by the liquid fuel board have shown that it is now possible to force the combustion of the oil, and that the greatest evaporation per square foot of heating surface secured with coal can be greatly exceeded by a liquid fuel installation of modern design, where provision has been made for atomizing the combustible and heating the air and oil.

"The supply of liquid fuel to naval vessels, which must be ready to proceed at any time to any port within their steaming radius, and cannot, therefore, depend on the commercial supply at comparatively few ports, may necessitate the establishment and maintenance of a chain of government oil stations.

"The evaporative efficiency of nearly every kind of oil per pound of combustible is probably the same. While the crude oil may be rich in hydrocarbons, it also contains sulphur, so that, after refining, the distilled oil has probably the same calorific value as the crude product.

"When steam is used as the atomizing agent, higher pressures are undoubtedly more advantageous.

"The consumption of liquid fuel cannot, probably, be forced to so great an extent with steam as the atomizing agent as when compressed air is used. This is probably due to the oxygen supplied by the air, while the steam displaces air, and, therefore, reduces the supply of oxygen.

"Under heavy forced draft conditions, and particularly when steam is used, it has not yet been found possible to prevent the escape of smoke from the smoke pipe, although special efforts were made to secure complete combustion."

Further tests with an installation on torpedo boats are to be made.

A rough summary of the data collected on the Hohenstein boiler tests shows the following results:

The steam pressure, 274 lbs. per square inch, was practically the same for all tests. The boiler had the same amount of heating surface in all the tests compared here.

	Coal.	*Oil.*
Calorific value of fuel, combustible in B. T. U.	15,435	19,481
Equivalent evaporation, in pounds of water, from and at 212° F., per pound of combustible, ranged from....................	9.52–11.77	10.77–14.43
Efficiency of boiler, in per cent, ranged from..	59.4 –73.4	53.4 –71.5
Efficiency of boiler, average.................	66.1	65.9
Steam used for atomizing oil, in per cent of total quantity of steam generated		1.06–8.54
Same, average		3.49

In the above tests, the heating value of the oil was 1.26 times that of the combustible in the coal. If the 19,481 units of heat in one pound of oil had been utilized in the same way as those in one pound of the combustible in the coal, the equivalent evaporation would have ranged from 12 to 14.8 pounds. That is, the superior heat value of the oil was not all realized.

Two tests, one with coal and the other with oil, the air pressure in the fire room being about 3.1 inches in the former, and 3.75 inches in the latter case, gave the following results, in per cent of the calorific values of the fuels:

	Coal.	*Oil.*
Heat utilized, or efficiency of boiler......................	59.4	53.4
Loss by escaping gases	32.3	36.4
Loss by imperfect combustion	3.4	1.2
Loss by radiation and other causes	4.9	9.0
	100.0	100.0

In comparing these results, it must be remembered that the coal was burned under trial conditions, which are not usually found in practice. The coal was of good quality, hand-picked and screened for nearly one-half of the tests, and the firing was

good. With the oil, however, the tests were carried on in about the same way as in actual practice, and the quality of the fuel was the ordinary commercial one.

Data for Liquid Fuel.

1 U. S. barrel of petroleum = 5.6 cubic feet = 42 gallons.
1 U. S. gallon of crude Pennsylvania petroleum = 7.3 lbs.; of refined petroleum, 6.6 lbs.
1 U. S. gallon of crude Beaumont, Texas, oil = 7.66 lbs.
1 metric ton = 7.1905 U. S. barrels of crude petroleum.
1 metric ton = 7.955 U. S. barrels of refined petroleum.

CHAPTER V.

COALING SHIP. BUNKERS.

Coaling Ship.—As the Navy Department has now contracts with coal dealers in nearly all the important ports of the world, there is, generally, no trouble in getting good Pocahontas or Welsh coal. The coal should always be inspected by an engineer officer, and, if possible, a quantity tried before purchase. The fullest particulars possible of the coal received should be noted.

Before coaling, the condition of the bunkers and of all water-tight openings in them should be ascertained and all unauthorized materials taken out. (Reguls.) The amount of coal in each bunker should also be accurately ascertained and noted.

Amount of Coal Received.—Except where the coal comes off in lighters, the contents of which are easily measured, and where the number of cubic feet to the ton is fixed by custom or rule of the port, as, for instance, at Port Said, Egypt, where coal must be received at 40 cubic feet to the ton, the coal should always be weighed. This is either done on shore while the lighters are filling, or on board during coaling, the former being preferable. A sufficient number of the filled bags, baskets, or buckets must be weighed, usually one out of every ten, to insure a fair average weight for all those that have been tallied as they go into the lighter or come on board. A rough check on the amount thus calculated is applied, when the bunkers are to be filled, by taking the total capacity of the bunkers and the estimated amount on hand before coaling (making allowance for the boal burned during coaling). The difference should be somewhat near the amount received, as calculated from the tallies and their average weight.

At best, the amount of coal received on board cannot be ascertained accurately. Experience, combined with care in tallying and weighing the coal received, and in estimating the coal in the bunkers, and watchfulness of the various methods used while coaling, will reduce the error to a reasonable quantity.

Wet Coal.—If coal must be taken on board in rainy weather, it

should be put in the bunkers which can be used first. Coal containing much sulphur in the form of pyrites, if it must be taken on board, should not be moist, as, in that condition, heat and gas are liable to be generated soon. When through coaling, the joints of bunker plates and coaling ports should be carefully made, so that no water may get into bunkers and the coal kept as dry as possible.

Bunkers.—The bunkers of warships are usually numerous and small, and generally arranged in a fore-and-aft line between the machinery compartment bulkheads and the ship's sides. Where there are two tiers of bunkers, as in the larger ships, one above and the other below the protective deck, the latter has openings in it through which the coal from above is put into the *feeding bunkers* below. The capacity of each bunker and the corresponding weight of coal that can be stowed in it under service conditions are calculated, and the bunker plan, with these data on it, forms one of the ship's drawings. The number and spacing of frames in each bunker and the principal dimensions should also be given, so that the estimate of coal on hand may be obtained with greater facility and smaller error.

If the bunkers of a new ship were carefully filled during the first coaling, taking time to trim and weigh the coal, the standard capacity of each bunker would then be known for the particular coal used. When opportunity offers, this should be done for one bunker at least, picking out a fairly large one, with as many straight sides to it as possible, in order to ensure greater accuracy in measurement.

Coal Account.—As the coal is taken from the bunkers in small quantities, it cannot be expected that the expenditure for any given time, as shown by the steam log, will be equal to the amount actually used. Provision for the adjustment of this discrepancy is made in the steam log in the following manner:

The coal as it is taken from the bunker is filled into the coal buckets provided and then put before the furnaces. The number of buckets used per hour is noted and given to the machinist of the watch. Just before leaving port, or when new coal is received, twenty buckets of coal are accurately weighed, and the average net weight of coal per bucket obtained. This is increased by from 5 to 10% for the weight to be charged per bucket in the hourly account in the steam log. Whenever the quantity of coal

on hand is estimated in the bunkers, the difference, if any, between this amount and that shown by the coal account is applied as a percentage to all days between this date and that of the last estimate. The difference is expended or taken up on the day of making the estimate, and the charge per bucket for the succeeding days is increased or reduced, if necessary, until another estimate is made. The blank form at the top of the page of "Remarks" in the steam log shows how the estimate and correction are to be entered, so that the hourly and daily accounts already made need not be altered.

By making the examination or estimate of the bunkers sufficiently frequent, as the regulations require, and using all care and precautions in recording the coal taken out of the bunkers, the coal account can generally be kept sufficiently accurate for practical purposes.

On long runs with a limited coal allowance, rivalry between the watches, either encouraged from the outside or existing among the men, generally leads to great errors in the coal account, and should for that reason not be allowed.

In some ships, the floor space in the fire room is so small that the use of coal buckets for measuring the coal is almost impracticable, and the coal is expended by shovelsful, so many to a bucket. In this case, the charge per bucket may be safely made large in order to avoid undue error.

Ventilation of Bunkers.—It is now generally conceded that air should not be admitted through the body of the coal, but only to the surface. Ventilating pipes, running from the tops of bunkers to the smoke pipe casing, are now usually fitted to permit the free escape to the atmosphere of the gases as they are formed. Fresh air inlets to the surface of the coal are provided at the same time, these being as far as possible from the outlets. If these openings are kept clear, no trouble from an accumulation of explosive gas is likely.

When coal bunkers are not provided with permanent ventilating pipes, the top or deck bunker plates should be removed at least twice a week, and oftener, if convenient, and kept removed for a period of several hours each time. (Reguls.)

No open light is to be used inside the coal bunkers until the absence of explosive gas has been proved by a miner's safety lamp; and special precautions in this respect are to be taken for a few days after coaling. (Reguls.)

Temperature of Bunkers.—Places for the insertion of thermometers are now usually provided in each bunker, and the temperature of filled bunkers should be taken every watch and entered in the steam log. Should any sudden or abnormal increase in the temperature of any bunker be noticed, the ventilation of that bunker should be increased. If this is not sufficient, the cause of the rise in temperature must be found.

The electric bunker alarms fitted on most of our ships are generally unreliable. When in good working order they will sound when the temperature rises, but they as frequently sound when there is no rise. The mercury in the little cups, the expansion of which makes the electric contact to sound the alarm, is frequently knocked out by a shock, so that the apparatus will not work.

Other Bunker Fittings.—Valves are fitted to the bunkers by means of which they may be drained. Branch steam pipes, usually 1½ inches in diameter, are led to each bunker for the purpose of extinguishing fire. In the later ships, the pipe leads to the floor of the bunker and its end is fitted with a nozzle, so that the steam will be distributed throughout the coal. A valve is fitted to each pipe at the bunker bulkhead.

Bunkers for Liquid Fuel.—As none of our ships is yet fitted to use liquid fuel, the particular construction of bunkers for its storage need not be detailed. It will be necessary to notice only some of the more important points that must be guarded against when stowing this fuel.

1. Ample means to insure the free escape of gases, and to permit the free movement of the liquid without damage to the bunker, when the latter is reduced in capacity, as by the grounding of the ship, or when, on account of the expansion of the oil, it becomes too small. This expansion may be taken as one per cent of the bulk for every 20° F.

2. Separation and removal of the water contained in the oil, before the latter is pumped out.

3. Special bulkheads and special closer riveting of the joints, owing to the penetrating power of the petroleum.

4. Removal of the bunkers as far as possible from the boilers.

CHAPTER VI.

NATURAL AND FORCED DRAFT.

Natural or Smoke Pipe Draft.—It has already been shown under "Combustion" that the draft or the supply of air to the fires, with the smoke pipe only, depends on the difference in the densities of the air outside, and of the hot gases inside of the pipe, and that a certain quantity of air is necessary to burn a given quantity of fuel. We should, therefore, be restricted, in any given ship, to a given amount of steam produced by the boilers, the variation in this amount being small and depending chiefly on the weather conditions, and, consequently, be limited to a certain speed, as was the case in the earlier warships.

If the height of the smoke pipe were made greater, the draft would be increased, and, consequently, the amount of coal burned or the rate of combustion be greater. This rate of combustion is expressed in *pounds of coal burned per square foot of grate surface per hour.* But the smoke pipe cannot be lengthened indefinitely, the usual height on large ships now being about 100 feet above the grate surface. With this height, the coal consumption may be as much as 25 pounds per square foot of grate per hour under natural draft.

Increasing the number of boilers would increase the amount of steam produced, but the weight and space of the boiler installation would also increase. But, as the weight of and the space occupied by the machinery (which includes engines, boilers, and auxiliaries) on board modern warships are very important factors, the number of boilers is limited.

We must, therefore, increase the steam-producing power of the given boilers by artificial means, and this is done by increasing the rate of combustion by the use of some system of *forced draft,* which term includes all degrees of increase in the rate of combustion when produced by artificial means. Some form of forced draft is all the more necessary on most modern high-powered ships, as, owing to the fitting of a protective deck and the very

restricted openings left in it for air to reach the fires, natural draft is almost an impossibility.

Forced Draft.—Not only is the steaming power of the boiler increased by the use of forced draft, but, when moderately applied, the efficiency of the combustion is increased, as has been pointed out before.

The systems now in use are:

1. Steam jet. 2. Closed ash pit. 3. Induced draft. 4. Closed fire room.

Steam Jet.—This system is the easiest to fit, but on account of its waste of steam, is used only on steam launches or small boats, which can easily renew the fresh water lost. The steam is drawn from the boiler and blown through small holes in a pipe into the

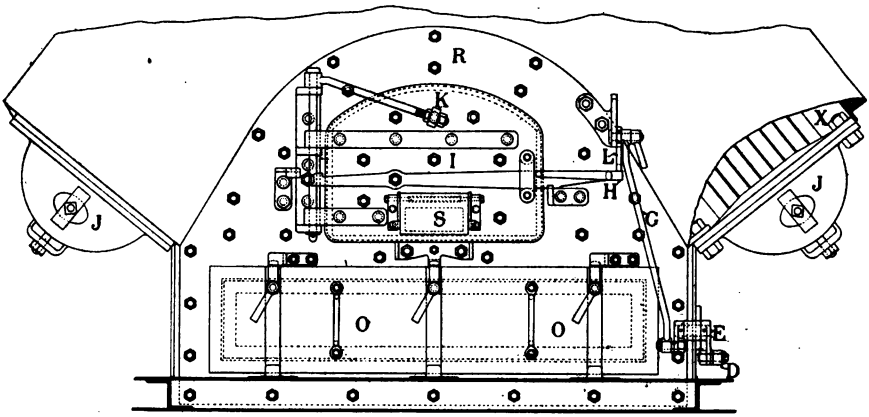


FIG. 9–1.

base of the smoke pipe, or above or below the grate, thus inducing a current of air to follow from the outside. To overcome the waste of steam, compressed air has been tried, but its use is very limited.

Closed Ash Pit.—Air is forced by centrifugal fan blowers, rotating at high speed, through ducts into the ash pit and furnace, the openings of which are closed tightly. It is an efficient and generally a simple system, and has the great advantages of permitting open fire rooms, and, as installed with tubulous boilers on our more recent ships, of giving proper and sufficient ventilation to the fire rooms. The moral effect on the fire room force of the former advantage and the physical effect of the latter cannot be given too much prominence.

With shell boilers, as on the "Yorktown" and "Bancroft," the air ducts are led under the fire room floor to the front of each ash pit, where they end in a casing, which covers the ash pit opening and which is provided with a door in front and a damper on a level with the bottom of the ash pit. Suitable openings are provided in the dead plate to permit some of the air to enter above the grate. As the air drawn in by the blowers does not pass through the fire room, the ventilation is not good, and, as the

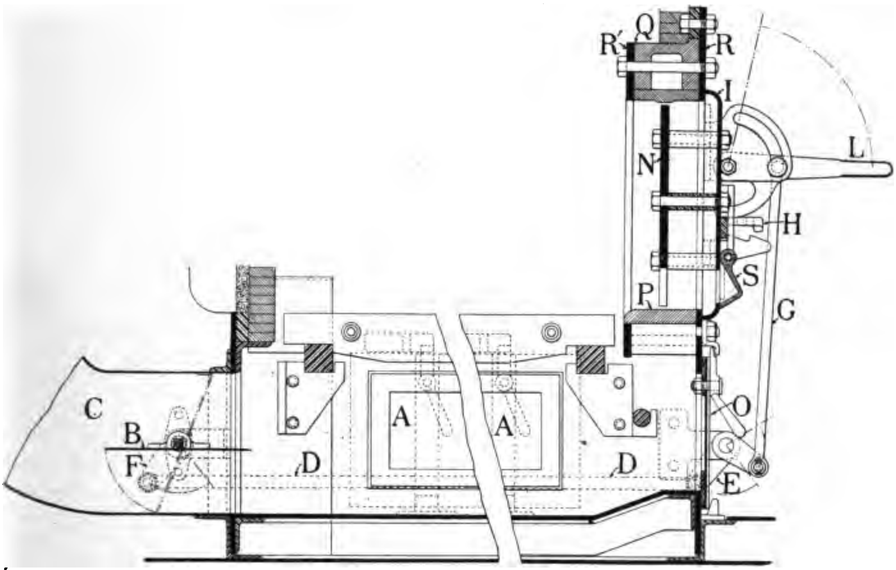


FIG. 9–2.

ducts must be led to the fronts of the ash pits, the installation is somewhat complicated.

In the recent ships, having tubulous boilers to which air can be admitted at the back of the ash pit, the installation is simpler and the ventilation much better. The blowers, usually one for two boilers, are placed at the tops and backs of the boilers, and draw the air from the upper part of the fire room and discharge it into *draft chambers.* These are formed by enclosing the space between the back of each boiler and the adjacent bulkheads. As the fire room ventilators and ash hoists are always open, there is a constant supply of fresh air into the fire rooms, which, passing through the hottest part of the fire room on its way to the blowers, becomes slightly heated and thus aids combustion.

5

The supply of air to the fires is regulated by the speed of the blowers and by a damper at the front or back of each ash pit. When the blowers are running and the furnace and ash pit doors are closed, the pressure of the air and hot gases in the furnaces is nearly equal to that of the air in the ducts or draft chambers. If a furnace door should then be opened without shutting the damper in the corresponding air duct, the hot gases would rush from the furnace into the fire room. Several serious accidents have happened in this way, and to prevent their recurrence through the thoughtlessness of the firemen, the furnace doors of many of our boilers using the closed ash pit system are fitted with a safety locking device.

The general principles of this system will be understood from Figs. 9-1 and 2, which show the arrangement on the Yarrow boilers of the "Nashville."

Fig. 9-1 is a front elevation of the lower part of the boiler, and Fig. 9-2, a vertical longitudinal section through the center of the furnace and ash pit.

The ash pit A A and furnace have been shortened for convenience. The furnace door is shown at I, the ash pit door at O, and the duct through which the air enters, at C.

The door O is made air-tight by an asbestos gasket secured around its edges, this gasket being slightly compressed when the door is lowered into the sockets below and the three wedge bolts above are secured by their handles. The furnace door I fits closely around its edge to the furnace front and is held in that position by the handle H. The small slicing door S, being of heavy cast iron, allows no air to escape, except a little under very strong draft.

The damper B at the back of the ash pit is shown open, the dotted lines showing its position when closed. Connected to the spindle on which B moves, and on the outside of the boiler casing, is the crank F, which is moved by the handle L, to the right of the furnace door, by means of the rods D and G and the cranks at E. L has a curved projection on its under side, which, in the position shown, is held firmly against the top of the furnace door handle H. L has motion upward in the slotted arc and can be held firmly in any position by the handled lock nut to the right. H cannot be raised or the furnace door I opened, until the lock nut on L is eased and L raised, and then B must close and the air be shut off.

Howden's System.—This is a closed ash pit system, but combined with means for heating the air before it reaches the fires. The air heater consists of a nest of thin tubes fitted in the uptake, the products of combustion passing through the tubes and

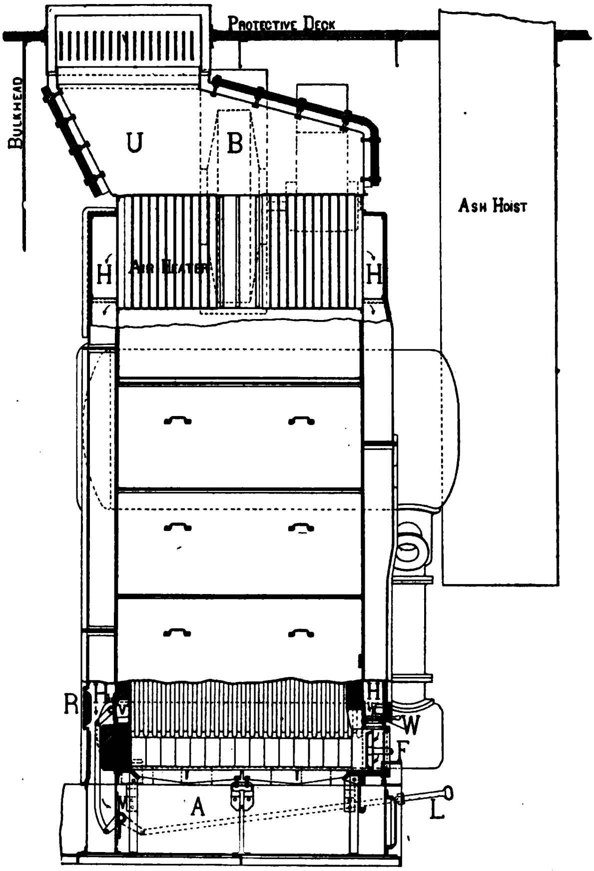


FIG. 10.

the air for combustion around them. Special provision is made for the regulation of the air supply above and below the grate.

When the system is fitted to shell boilers, the grate is made shorter than usual and it is level or slightly raised at the back. In addition to these changes, both generally conducive to economy, the boiler tubes are fitted with *retarders*. These consist of strips of thin metal, twisted into a spiral, which are pushed

loosely into each tube. By retarding the egress of the gases, and thus keeping them in contact with the tube surface for a longer time, more heat is abstracted, and increased efficiency follows under forced combustion.

All of the ducts and casings must be kept air-tight, or the hot air will be forced into the fire room.

As this system utilizes all of the means which have been shown to be necessary to economy and perfect combustion, it follows that, when it is properly worked, the boiler efficiency will be increased.

Fig. 10 shows a side elevation, partly in section, of the arrangement of this system on one of the Thornycroft boilers of the battleship "Ohio." The boiler casing is shown complete in the middle part of the boiler, and is removed at the top and bottom. Another view is shown in Plate X.

B is the blower situated at the top and on one side of the boiler. The air heater is composed of 416 tubes, $2\frac{1}{2}$ inches in diameter, and has a heating surface of 793 square feet, or a little over ten times the grate surface. Air ducts H, H, are built on the front and back of the boiler to guide the air to the furnace fronts and to openings in the back wall and back of ash pit, as shown by the arrows. The products of combustion pass upwards from the furnace, around the boiler tubes, and through the tubes of the air heater into the uptake U.

Above each furnace door F is an opening covered by a flat valve W, which can be moved by a handle from the outside. The supply of air to the front part of the fire can thus be regulated. In the back wall, some distance above the grate, there is a perforated plate extending almost the whole width of the grate. By means of the damper V′, the supply of hot air from H to the top of the fire can be regulated. The main supply of air enters the ash pit A through the large damper V. Both dampers are worked together by the rod L from the front of the boiler. A handhole R is provided in the back of the casing for the easy examination of damper V′.

The sister ship "Missouri" has Thornycroft boilers and air heaters, through which air passes from the closed fire room to the back of ash pits. A good comparison between this and Howden's system under service conditions will, therefore, soon be available.

Induced Draft.—This name applies properly only to the system by which an upward current of air through the boiler is induced

by means of a blower at the base of the smoke pipe, or in the uptake of each boiler. The blower required is much larger than that for the closed fire room system, and is very liable to dangerous overheating. When a separate blower is fitted in each uptake, the draft can be regulated for each boiler separately as required. British naval experience showed that, while on other grounds there is little choice between this induced, or Martin's, and the closed fire room system, the great advantages of working with an open fire room remain with the induced draft.

The most prominent ships fitted with this system are the British battleships *Magnificent* and *Illustrious.*

Ellis and Eaves' System.—This is an induced draft system with closed ash pits, combined with means for heating the air for combustion. In the latest type of this system, the air is drawn past the outside of the heating tubes, as in Howden's. As the pressure of air is less in the casings and ducts, these need not be so carefully fitted. Arrangement for air distribution above and below the grate, similar to Howden's, but better, are made.

With this system, Howden's retarders and Serve boiler tubes are always used in shell boilers, and the patentees attribute a great part of the economy to the use of these tubes. The Serve tubes are like the ordinary boiler tubes on the outside, but on the inside, there are some seven or eight radial ribs, projecting about one-fifth of the external diameter of the tube, which increase the heat-absorbing power of the tubes and thus the boiler efficiency. The weight of a Serve tube is about twice that of an ordinary boiler tube and the cost is greater.

The grate is level for ordinary rates of combustion, and raised at the back for the higher rates. Provision is also made for admitting a very small quantity of cold air from the fire room to the under side of the grate.

The two systems of heating the air before admission to the fires, which are described above, have shown an economy in working, as is to be expected from any system by which the loss of heat in the smoke pipe gases is reduced. But just how much is due to the heating of the air alone, without reference to the other aids used, it is difficult to tell.

Closed Fire Room System.—This system is now more generally in use than any of the others, although a tendency to open fire rooms is now apparent. In this system, the air is forced by blow-

ers direct into the fire room, all hatches and doors being closed air-tight, and must find its way out through the furnaces and ash pits. Although an efficient system for obtaining high rates of forcing, it does not seem to have any advantages at the rates now adopted for all ships other than torpedo boats or destroyers. It has several disadvantages.

The temperature of the fire room is usually higher than with open fire rooms. The arrangement of air locks, ventilators, bunkers and special air-tight bulkheads is costly and the weight considerable. The men are imprisoned in the fire rooms by numerous doors and hatches and must work in an atmosphere surcharged with coal dust.

Communication between the fire rooms, or between the compartments under pressure and those not under pressure, is effected by means of air locks. These are small spaces, each closed by two doors. After passing through the first door, it is closed before the second one is opened, thus reducing the loss of pressure to an inappreciable quantity.

In order to reduce the fire room space which must be kept under pressure, special air-tight bulkheads are often fitted. With tubulous boilers, the ash pit and other air doors in the casing are so arranged that they will close automatically in case of a sudden outrush of steam, such as would follow the bursting of a tube. One form of this door is shown at A′, plates V and VI, the axis on which it turns being above the middle of the door. It is held open in any position by means of the counter weight at the top of door and by the notched lever. It is closed automatically by the excess pressure on the larger area. In another form, the door is inside the casing and hangs from supports which are well above the opening. The air pressure swings the door open and any steam pressure would close it.

Air Pressure Gages.—The usual method of measuring the air pressure or the draft, is by the difference in level of the water contained in the two legs of a glass U-tube, one end of which is open to the atmosphere and the other to the fire room or air duct under pressure.

Fig. 11 shows the ordinary air pressure gage, without its case. The top of leg A is led to the atmosphere when this gage is used with the closed fire room system, B being open to the fire room. When the closed ash pit system is used, A is connected to the air

duct near the ash pit, B being then open to the atmosphere in the fire room. Scale C is graduated in fractions of an inch to represent the difference of level or pressure, the zero mark being in the middle of its length or heighth. When there is no pressure, the water level should be at zero. If it is not, water should be added or taken out in order to facilitate the reading of the scale. It will be readily understood that a pressure exerted on the water level in B, which will force it down 1 inch, will raise the level in A 1 inch, and that the pressure is equal to that of a column of water 2 inches high. This is, therefore, the air pressure in the fire room or air duct.

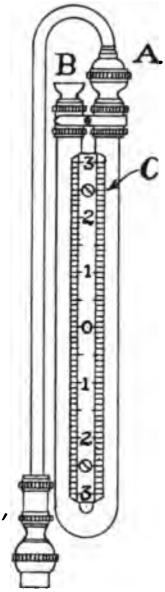


FIG. 11.

The scale may be more conveniently arranged for reading by adopting a sliding scale, graduated from zero up. When a difference in the two legs is shown, the zero of the scale is put opposite the lower level, and the reading of the air pressure taken from the higher level. No attention need then be paid to the quantity of water in the U-tube.

As the air pressure is frequently given in ounces (per square inch), it will be well to show the relation between inches and ounces.

A cubic foot of fresh water at 62° F. weighs 62.355 pounds; or, a column of water 1728 inches high and having an area of one square inch will weigh the same, or, in other words, exert a pressure of 62.355 pounds per square inch. Therefore, 1 pound per square inch would be exerted by a column $1728 \div 62.355 = 27.712$ inches high, or, 1 ounce per square inch, by a column of water 1.732 inches high. Taking the reciprocal of this, one inch of water column is equal to a pressure of .577 ounce per square inch.

Rate of Combustion.—So long as the amount of coal burned per square foot of grate surface under natural draft was sufficient for the requirements of the time, no especial effort was made to use forced draft, although all systems had been tried on naval vessels long ago. When, however, the desire for increased speeds became paramount, following the introduction of the torpedo boat, forced draft was again taken up about twenty-five years ago. The first object was to obtain higher powers with a given boiler, and later, to increase the economy of combustion.

Under natural draft, which is usually considered to be equivalent to an air pressure of about ½ inch, the rate of combustion varies from 15 to 25 pounds, the latter being reached under most favorable conditions. Following Mr. Thornycroft's experiments with a closed fire room, in which from 80 and 120 pounds and even more of coal were burned per square foot of grate, requiring air pressures of from 4 to 8 inches, the rate of combustion on larger ships was much increased for a time. But leaky tubes and a general failure of boilers led to a steady reduction of air pressure, so that now the limit allowed for our large ships is 1 inch. Torpedo boats and destroyers are not, of course, so limited, 5 and 6 inches being usual, although the limit for the later destroyers is 4½ inches. At this latter pressure, the rate of combustion varies from 55 to 65 pounds with the best coal. With air pressures ranging from ¾ to 1 inch the rate varies from 30 to 40 pounds.

The air pressure alone does not indicate the exact rate of combustion, but is used merely as a general measure. The thickness of the fire is an important factor, for a heavy fire offers a greater resistance to the passage of the air than a thin one, thus increasing the air pressure, but not necessarily the amount of air passed through the fire, or, in other words, the rate of combustion. With careful firing, in the manner previously explained, the same rate of combustion may be obtained with a lower air pressure. On the torpedo boat "Talbot," the air pressure has been reduced from about 2¾ to 1¼ inches, for the same speed of engine.

CHAPTER VII.

EVAPORATION.

In the preceding chapters, the manner of converting and applying the stored heat energy in the fuel has been shown. To thoroughly understand how this heat affects the water in the boiler, or how the steam is formed, a brief review of the subject of heat and its transfer is necessary.

When two bodies of unequal temperature are near each other, there is a constant tendency to equalize the temperature by a transfer of heat from the hotter body to the other. This transfer takes place in three ways—by radiation, by conduction, and by convection.

Radiation of Heat.—The heat radiated from hot bodies, like that of the incandescent furnace fire or a steam cylinder, is given off in straight lines, and the laws applying to radiant heat are the same as those for light. The radiation from the solid incandescent fuel is greater than that from the flame. The useful effect of the radiant heat from the solid incandescent fuel is confined to the furnace plates of shell boilers, and to the tubes immediately above or at the side of the fire in tubulous boilers. The heat radiated from the flame and gases has a useful effect in the furnace, combustion chamber, tubes and other heating surfaces, such as economizers and air heaters. In shell boilers, where the furnaces are surrounded by water, the loss from radiation is not so great as in tubulous boilers.

Conduction of Heat.—The transfer of heat by conduction may be between the particles of the same body, or between the particles of different bodies in contact. In the former case it is called *internal conduction,* an example of which is the transfer of heat in the furnace or tube plate from the fire to the water side. The transfer of heat from the fire or hot gases *in contact* with the surfaces of the furnace or tube plates, and that from the other side of these plates in contact with the water in the boiler, are examples of *external conduction.* The rate of transfer through the metal plates, by internal conduction, is very much greater than that from

the hot gases to the plate, or from the plate to the water. It is, therefore, of the greatest importance that the two surfaces of all plates that form the heating surface of a boiler should be kept clean, or in the best condition to absorb readily the heat on the fire side and to give it up on the water side. The effect of different deposits on these surfaces will be explained later.

The kind and thickness of the metal of the heating surfaces have little effect on the rate of the internal conduction, as this depends chiefly on the difference in the temperature between the two sides or surfaces of the plate.

Convection of Heat.—It is in this way, by the conveyance of flow of the heated particles, that all liquids and gases are heated. Since conductivity in liquids and gases is almost inappreciable, the transfer of the heat from one part of the liquid or gas to another is by convection or transportation only, and this can be effected by currents only. In other words, to secure a rapid and efficient transfer of heat through the plates of the furnace, combustion chamber, tubes and other heating surfaces, there must be free circulation of the gases in contact with one side, and of the water in contact with the other side.

Heat applied to the surface of water will not be transferred through the mass of the water, as no circulation will be set up. But, if the heat is applied at the bottom of a vessel containing water, the whole mass will become heated by the rising of the heated (and, therefore, less dense) particles and the sinking and substitution of the cooler ones. The currents thus produced will heat the whole and cause a uniform temperature throughout the mass. The same remarks apply to gases.

The freer the circulation of the water in the boiler and the better the mixture of the gases, the greater will be the efficiency of the boiler, other things being equal. To accomplish the former, many shell boilers are fitted with circulating plates in the water. Retarders in ordinary and Serve tubes break up the currents of gases and put fresh, heated surfaces of the gas in contact with the absorbing plate. Baffle plates among the tubes in tubulous boilers and the bridge wall in shell boilers have the same effect.

In order to secure the greatest efficiency in the transfer of heat from the gases through the plates of the heating surface to the water, these two fluids should move in opposite directions, thus bringing the coolest water opposite the coolest gases. Therefore,

the feed water should enter at the uptake end of the boiler and should circulate towards the furnace.

The above principle is applied in surface condensers and distillers, the cold water for condensing the steam entering near the place where the condensed steam leaves. The steam enters the condenser near the place where the circulating water, then somewhat heated, is discharged.

Formation of Steam.—When fires are started in the furnaces of a boiler, with the safety valves open, the particles of water in contact with the heating surfaces become heated, expand, and rise to the surface, being replaced by the cooler particles from above. As this heating goes on, which we can practically measure by a thermometer in the water, the whole mass is raised in temperature until the boiler is full of boiling water, giving off vapor or steam when 212° F. is reached. This point, called the *boiling point,* will always correspond to this temperature when the water is under atmospheric pressure, 14.7 pounds to the square inch. If, under these conditions, the application of heat were continued, the thermometer would remain stationary at 212° F. until all of the water had evaporated into steam of atmospheric pressure and a temperature of 212° F. It is apparent, therefore, that a large amount of heat has been absorbed by the water in changing from a liquid into a vapor or steam.

If the safety valves are closed when the boiling point is reached, there would be, at that instant, a boiler full of water at a temperature of 212° F. and under a pressure of 14.7 pounds, and the steam gage would show the pointer at zero, or no pressure *by gage.*

The safety valves being closed, the thermometer will show a gradual increase in the temperature of the water as the absorption of heat from the fire continues. If the steam gage is now observed, it will be seen that the pointer has left the zero mark and is rising, showing that there is a *pressure* in the boiler. This pressure is caused by confining the steam as it is formed in the steam space of the boiler, and, as we have started with the atmospheric pressure in it, the reading of the pressure, as shown by the steam gage, must be increased by 14.7 pounds to give the total, or *absolute* pressure.

Now, suppose that when the absolute pressure has reached 80 pounds, or 65.3 pounds by gage, the stop valves are opened and the engine started and run at such speed as to keep the pressure in

the boiler *constant*. We should then find that while heat is being absorbed continuously for the production of steam of 80 pounds pressure, the temperature of the water remains at 311.8° F., instead of at 212° F., when the pressure was that of the atmosphere only.

Again, if the conditions were fixed to produce steam constantly at 160 pounds absolute, or 145.3 pounds by gage, the temperature of the water would remain at 363.4° F.

Boiling Point.—From the above examples it is seen that the temperature at which the water is converted into steam, or its *boiling point*, does not remain constant, but that it bears some relation to the pressure. If we had started with a pressure of 80 pounds absolute on the surface of the water, no boiling would have taken place until the temperature of the water had been raised to 311.8° F. There is then a certain boiling point for each pressure and which increases with the pressure. The relation between the temperature and the pressure has been determined experimentally by Regnault and others and is given in Table II[1] at the end of this book.

As the boiling point, or temperature of the steam, and other data are needed usually for a certain pressure as read on the steam gage, it must not be forgotten that the temperature depends upon the *absolute pressure*, or the pressure above a perfect vacuum. Table II is made out for absolute pressures only, so that when using it 14.7 pounds must be added to the reading of the steam gage.

In Table III the data have been arranged for pressures below the atmosphere, in *inches of mercury*, or, as these are commonly called, *inches of vacuum*. It is in this form that pressures below the zero of a steam gage are used and marked on similar gages, called *vacuum gages*. The data were compiled from Peabody's tables by interpolation, and are accurate enough for all practical purposes.

The boiling point of water is increased by salts dissolved in it, as in sea water, but not by bodies in mechanical suspension only, as sand in river water. For sea water, which contains about $\frac{1}{32}$

[1] By kind permission of Prof. C. H. Peabody, from his "Tables of the Properties of Saturated Steam and other Vapors," 1890. The complete tables, arranged for pressures and temperatures, are now generally used in the naval service.

part of solid matter, the boiling point is 213.2° F. under atmospheric pressure, and this is raised as the proportion of salt or solid matter increases, so that with a concentration of $\frac{4}{32}$ the boiling point, under atmospheric pressure, would be about 217° F. But it has been proved by experiment that the steam produced from any saline solution is that of pure water (this fact being taken advantage of in distilling fresh water), and also that the temperature of the steam formed at higher pressures is the same as that of steam formed from fresh water at the same pressure.

Sensible and Latent Heat.—From the explanation given of the formation of steam, it is apparent that some heat has been expended, of which the thermometer gives no record, in changing the state of the water from a liquid into steam of a certain pressure, and which has the same temperature as the water in contact with it. The quantity of heat which the thermometer measures (not exactly, however, as will be seen later) is called the *sensible heat,* while the heat expended or transformed in changing the state of the water (or any body), without changing its temperature, is called *latent heat.* According to the accepted theory, the latter quantity of heat, in the case of steam, is expended chiefly in overcoming the cohesive force of the molecules of the water, which resists the change to steam, and, in a lesser degree, in increasing the volume during the formation into steam. As work has been done in converting the water into steam, the heat energy absorbed is in the form of potential energy. And as, by the first law of thermodynamics, heat and mechanical energy are mutually convertible, the so-called latent heat can be recovered either as heat or work, when the change of physical condition from steam to water is effected without lowering its temperature.

Joule's Equivalent and the Unit of Heat.—The first reliable determination of the relation between heat and mechanical energy was made by Joule in a series of experiments on friction. He deduced that the heat necessary to increase the temperature of one pound of water one degree from the freezing point, from 32° to 33° F., required an expenditure of 772 *foot-pounds* or *units of work,* or that the mechanical equivalent of one *unit of heat* was 772 foot-pounds. The above unit of heat, designated generally by the letters B. T. U., and Joule's equivalent, 772, are often used. The later experiments of Rowland, at Baltimore, show the equivalent to be 778, and this value is used in the text of this book.

The figures given in Table II for the sensible, latent and total heats were calculated by Professor Peabody, who used as the standard unit of heat the quantity required to raise one pound of water from 62° to 63° F., the first temperature being about the mean temperature of the air during experimental work. This quantity of heat is easily verified, while that required to raise the water from 32° to 33° F. has not been found experimentally.

The following data are given for comparison with metric measurements.

The French or metric unit of heat is called *calorie,* and is the heat required to raise one kilogram of water 1° C. It is equal to 3.968 B. T. U. One B. T. U. is equal to 0.252 calorie.

One calorie is equivalent to 423.55 kilogram-meters, or metric units of work.

The British mechanical equivalent, 772 foot-pounds, equals 10.67 kilogram-meters, and Rowland's equivalent, 778 foot-pounds, 426.9 kilogram-meters.

Specific Heat of Water.—It was stated above that the sensible heat of water was measured by the thermometer, but not exactly. This is due to the fact that the capacity for heat, or *specific heat,* or the quantity of heat necessary to raise the temperature of water 1° F., is not the same at different parts of the scale of temperatures. This is caused by the small expansion of the water as it is heated. Professor Peabody investigated the experiments of Regnault and Rowland, and from a combination of their results found that below 104° F. the specific heat was variable, and above that temperature it was as follows:

104 to 113° F., the specific heat is 1.

113 to 311° F., the specific heat is 1.008.

311 to 392° F. and above, the specific heat is 1.046.

These quantities have been employed in calculating the heat of the liquid in the table on the properties of steam.

The usual standard for the specific heat of water is taken as the quantity of heat required to raise its temperature from 32° to 33° F., and is taken as unity.

From Table II the sensible heat of water at 212° F. is 180.8 units from 32° F., while the thermometer registers a rise of $212° - 32° = 180°$ only.

Again, the sensible heat at an absolute pressure of 230 pounds is 367.1 units, while the thermometer shows a rise of 361.7° only.

Total Heat of Vaporization.—This is the quantity of heat required to raise a unit weight of water from the freezing point to a given temperature t, and to evaporate all of it at that temperature; or, for our scale, to raise one pound of water from 32° F. to the temperature t, and to evaporate it at that temperature.

From his experiments, Regnault deduced the following formula, arranged for our scale:

$$\text{H} = \text{total heat} = 1091.7 + .305 \ (t\text{-}32),$$

or, as taken usually, $\text{H} = 1082 + .3t$, which gives approximately accurate results when no tables are available.

Latent Heat, or Heat of Vaporization.—As stated above, this is the heat expended in transforming the water into steam at a constant temperature and pressure. This quantity cannot be measured, but is found by taking the difference between the total heat, H, of the transformed water or steam, and the sensible heat, S, or the heat required to raise the temperature of the water to the boiling point. H and S, as we have seen, were both found by experiment. If L represents the latent heat, we get

$$\text{H} = \text{L} + \text{S}, \text{ or } \text{L} = \text{H} - \text{S}.$$

From an inspection of Tables II and III, it will be seen that the latent heat decreases as the temperature of the boiling point increases. But, as the sensible heat increases more than the latent heat decreases, the total heat rises as the temperature of the boiling point, or the pressure of the steam, increases. This is, of course, evident from Regnault's formula for the total heat.

Saturated Steam and its Properties.—It is known that there is only one pressure and one density of steam, as generated in a boiler, for each temperature, and that these increase with the temperature. Saturated steam is the normal condition of steam generated from the water with which it is in contact, and, for any given temperature, the density of the steam will be the greatest it can have and still remain vapor, and the corresponding pressure will be the greatest that the steam can exert.

The steam is, therefore, in such a condition that any reduction in the heat will cause some of the steam to condense, or resume its liquid state, and any increase will change more water into steam.

Wet steam.—Saturated steam, in some boilers, may be generated very nearly perfectly *dry,* that is, without being mixed with any liquid water, but, as a rule, the boiling of the water is more or less

violent, so that some unevaporated water is carried up with the steam as it is formed. The vapor of the water is, of course, saturated steam, but the mixture of saturated vapor and liquid water is called *wet steam.*

In well-designed boilers and under good conditions, the amount of entrained water may be only 1% or less, while in badly-designed boilers and under poor conditions it may be 6% or more and be the source of serious trouble in the boilers and engines.

Superheated Steam.—Suppose that all the water in a closed boiler could be evaporated with safety, and that, after the last particle of water had been transformed into steam, heat were still applied. We should then have a fixed or constant volume of steam, and it would be found that both the temperature and pressure of this steam would increase, while its density would, of course, remain stationary. Or, if a portion of saturated steam from a steaming boiler is removed from contact with the water and is then heated in a separate chamber or space, we shall find that its volume and temperature will rise, the pressure remaining the same as that of the saturated steam in the boiler.

In the first case, the pressure and temperature are higher than those for the same volume of saturated steam; in the second case, which is the only one that need be considered here, the volume and temperature are greater than those for the same pressure.

Steam in this condition is called *superheated steam,* and must naturally be perfectly dry. Superheated steam approaches to the condition of a perfect gas, and, in all investigations of its action, it is generally assumed to be such, more particularly when the superheating amounts to over 20° F. above the temperature of the saturated steam. The specific heat of superheated steam under constant pressure is .48, and being taken as that of a perfect gas, is constant.

The total heat of superheated steam for any given pressure is equal to the total heat in dry steam of the same pressure plus the product of the specific heat of steam and the number of degrees its temperature has been raised above that corresponding to the pressure of the dry saturated steam, or,

$$H'' = H + .48\,(T - t).$$

Formation of Steam under Constant Volume.—Steam for use is generated in a boiler *under constant pressure,* but, when raising

steam from cold water with the safety and stop valves closed, and while changing the pressure from one point to another, it is generated *under constant volume.* As these steps are preliminary to the regular formation of steam under the desired working pressure, and the amount of heat expended is comparatively small, it will be sufficient to say that the temperature and pressure both increase in the same manner as when the steam is formed under constant pressure, the volume and density being, of course, different for the same pressure.

Total Heat of Wet Steam.—From the definition of wet steam, this is part saturated steam and part water heated to the boiling point corresponding to the pressure. The part of the water that has been changed to dry steam is designated by Q, or the *quality* of the steam, and is the percentage of dry steam in the total quantity of water and steam. It is evident that all of the water must be heated to the boiling point corresponding to the desired pressure, while only Q parts are changed to steam, and $1 - Q$ are carried up as water. The general formula for total heat in one pound of dry steam, in which case $Q = 1$, will become, therefore, when one pound of wet steam of a quality of Q is produced,

$$H_1 = Q(L + S) + (1 - Q)(S) = QL + S.$$

Example: Find H, L and S for dry steam, when the steam gage shows 135.3 pounds, the feed water being 32° F.

From the table, $L = 861.2$; $S = 330$; and H, therefore, $= 861.2 + 330 = 1191.2$ B. T. U.

Now suppose that instead of dry steam, the quality of the steam is .97. Then

$$H = .97\ L + S = .97 \times 861.2 + 330 = 1165.4 \text{ B. T. U.}$$

Heat Required to Produce Steam when Feed Water is at a Temperature other than 32° F.—In the table, as explained before, the calculations are based on a temperature of 32° F. for the feed water. But, in practice, this temperature is always higher, and, therefore, less heat will be required to raise the feed water from its entering temperature to that corresponding to the pressure.

Example: How many thermal units are required to produce steam at a pressure of 135.3 pounds by gage, the feed water being admitted at 160° F.? Quality of steam .97.

As before, S, or the heat of the water corresponding to a pressure of 150 pounds absolute, is 330. But the heat of the feed water, S′,

corresponding to a temperature of 160° F. is 128.4 B. T. U. Therefore, to raise the feed water to the boiling point, 330 — 128.4 = 201.6 B. T. U. are required. S — S′ may be taken as the new value of S. QL is 835.4 as before.

Therefore, there will be required under these conditions only 835.4 + 201.6 = 1037 B. T. U.

Actual and Equivalent Evaporation.—In Chapter III the heating value of one pound of the average steaming coal was shown to be 14,162 B. T. U., and the average efficiency of the boiler .68. Therefore, 14,162 × .68 = 9630.2 units are taken up by the water for each pound of coal. But, to convert one pound of water from 160° F. into steam of quality .97 and a pressure of 135.3 pounds by gage, only 1037 units are required. Therefore, 9630.2 ÷ 1037 = 9.29 pounds of water were vaporized by each pound of this coal under the above conditions, or, the *actual evaporation* is 9.29 pounds.

The theoretical evaporative power of the fuel, from and at 212° F., is 14.66 pounds, and, as the efficiency of the boiler is .68, the real evaporative power of the fuel, from and at 212° F., is 14.66 × .68 = 9.97 pounds. This result would have been obtained directly by dividing 9630.2, the heat units absorbed by the water, by 965.8, the heat units required to convert one pound of water from a feed temperature of 212° into dry steam of the same temperature.

That is, the evaporation of 9.29 pounds of water under the actual conditions is *equivalent* to the evaporation of 9.97 pounds from and at 212° F., or, using the usual expression, the *equivalent evaporation from and at 212° is 9.97 pounds.*

Factor of Evaporation.—This is the ratio of the number of heat units in one pound of steam at the given pressure, and calculated from the temperature *t* of the feed water, to the number required to vaporize one pound of water into *dry* steam from and at 212° F. Or,

$$f = \frac{H - S'}{965.8} = \frac{L + S - S'}{965.8}$$

S′ being the heat units in the feed water at the temperature *t*.

For the above example, 1191.2 — 128.4 ÷ 965.8 = 1.101 is the factor of evaporation.

Tables are published giving the factors of evaporation for various steam pressures and temperatures of feed water. But, as these

assume that the steam produced in every case is *dry,* the method given above must be followed when Q is other than unity, or, if the factors are used, Q must be corrected as will be explained under "Boiler Tests."

The various steps in the transference of the heat energy of the fuel to the steam have been shown, and we now have the energy of this steam ready to do useful work in the various engines on board. We will next take up the various fittings on a boiler which are necessary for the supply and regulation of the water and steam, the different causes of corrosion in boilers, and the means adopted to preserve boilers.

PROBLEMS.

1. The analysis of a coal gives $C = .915$, $H = .035$, $O = .026$. (a) How much air per pound will be required to burn it? (b) How much water will one pound evaporate, theoretically, from a temperature of 120° F. to steam of 180.3 pounds' pressure, the temperature of steam of this pressure being 379.6° F.? (c) If one pound of this fuel, when used in another boiler, evaporated eight pounds of water, what would be the efficiency of this boiler?

2. Assuming that a boiler has an efficiency of 65 per cent, burns 1000 pounds of coal per hour, and is fed with water having a temperature of 175° F., what is the total weight of water evaporated per hour to steam having a temperature of 390° F.? An analysis of the coal gives $C = 91.5$ per cent, $H = 3.5$ per cent, and $O = 2.6$ per cent.

3. The following is a partial record of the test of a certain boiler for efficiency: Temperature of feed, 80° F.; temperature of steam, 300° F.; pounds of feed water used, 8000; pounds of coal used, 1000. The feed water was kept at a constant level in the gage glass and an analysis of the coal gave its composition as follows: Carbon = 90 per cent, hydrogen = 8 per cent, and oxygen = 1.2 per cent. What was the efficiency found to be? The test lasted one hour.

4. A mineral oil is by analysis .85 C, .11 H, .2 O. Assuming that pure carbon represents a fair sample of good oil, how will its evaporative power compare with that of the mineral oil?

5. A ton of coal requires 44.5 cubic feet of bunker space to stow it, and the specific gravity of mineral oil is .99. Assuming the average thermal value of the coal to be equal to that of pure carbon,

how much space could be saved if oil tanks were fitted in a ship which has a bunker capacity of 1000 tons?

6. A boiler is tested for 24 hours and during that time burns 235 pounds of coal. The feed has a temperature of 100° F. and 30.4 cubic feet of water are evaporated to steam having a temperature of 300° F. The composition of the coal is 80 per cent C, 10 per cent H, and 6 per cent O. What was the result of the test as to efficiency?

CHAPTER VIII.

CORROSION, AND CARE AND PRESERVATION OF BOILERS.

As the subject of keeping the boilers of a warship in the most efficient condition for the longest possible time is, probably, the most important one which affects the efficiency of a ship as a whole, it is necessary to study carefully and carry out the means which experience has suggested, not only to prolong the life of the boilers, but to keep them in the highest state of efficiency at all times.

It is not only a knowledge of the subject of corrosion, its effects, and the methods employed to reduce or prevent the latter, that is necessary, but also a thorough understanding of the effects that can be produced by the improper management of boilers under steam. For the reduction or prevention of the effects of corrosion, the officer in charge of the engineer department is directly responsible; the prevention of the effects of improper management is largely in the control of the commanding officer. While no care and knowledge, however great, can prevent the gradual wear of boilers, and the consequent reduction of the original steam pressure, a thorough appreciation of the subject will prevent a premature deterioration or renewal of the boilers.

THE NATURE OF CORROSION AND THE COMMON AGENTS OF CORROSION.

The process of corrosion of iron or steel is chiefly one of gradual oxidation, and consequent wasting away, of the metal.

The three oxides of iron, all of which appear in some form or other, either as producing, or as the product of, corrosion, are ferrous oxide, FeO, ferric oxide, Fe_2O_3, and the black or magnetic oxide, Fe_3O_4. Ferrous oxide is never seen in nature, because upon exposure to oxygen it becomes further oxidized. It is always present in minute, but often important, quantity in iron and steel, and plays some part in certain kinds of corrosion. Ferric oxide has a brownish-red color, characteristic of common rust, of which it is the chief constituent. Magnetic oxide, so called from its magnetic qualities, has a dull lilac-blue color. Together with ferric oxide it

forms a scale on iron, when heated in the presence of oxygen to a temperature above 900° F., and plays an important part in galvanic corrosion. This scale is known as "mill scale," and is produced during the rolling of iron or steel plates and their subsequent working. Upon long exposure to the weather, this mill scale becomes gradually converted into common rust, losing its magnetic properties.

The exact nature of the product of corrosion of iron or steel depends upon the circumstances under which it is formed. Slow corrosion at normal temperatures with plentiful access of air invariably produces ferric oxide, which with a certain proportion of moisture forms common rust. If corrosion be rapid with a deficient supply of oxygen, a certain proportion of ferrous oxide is formed; this may be observed in the rust formed on plates immersed in sea water, especially warm sea water. Corrosion taking place in solutions of corrosive gases or salts, or by galvanic action, results in certain chemical products which are formed by the decomposition of the solution and which may be found in appreciable quantity.

Air, Carbonic Acid, and Impurities in Water.—Laboratory experiments have shown that the presence of both air and water, or moisture, is necessary to cause corrosion. A clean iron plate immersed in pure water from which the air has been expelled will not become oxidized; neither will rust be formed on a clean iron surface in ordinary air if actual deposition of moisture on the surface of the iron be prevented, but if rusting has commenced it will continue under these circumstances. Also, iron in dry carbonic acid gas is not affected, but in moist CO_2 with oxygen present, rusting goes on rapidly. The action is supposed to be that CO_2 and the iron form ferrous carbonate, which, if oxygen is present, is converted into Fe_2O_3, liberating the CO_2 and permitting it to act thus continuously as a carrier of oxygen to the iron. Other impurities in water to which iron is exposed, such as fatty acids, and the chlorides of calcium and magnesium common in sea water are also known to be active agents in promoting corrosion, especially under conditions of high temperature. Their action will be noticed later on.

Galvanic Corrosion.—If two electrically different metals be immersed together in a liquid which is a proper conductor, and an external circuit be completed between them by wire or contact of the metals, themselves, an electric current will pass between the

metals through the liquid and through the external circuit, its strength depending on the difference of electric potential of the metals and the conductivity of the liquid. Besides decomposing the liquid through which it passes, the current causes a gradual wasting away by oxidation of the electro-positive metal and the accumulation of bubbles of hydrogen gas upon the surface of the electro-negative metal. This wasting away of the electro-positive metal is known as galvanic corrosion. The nature of the exciting liquid in certain particulars affects the rate of galvanic corrosion very materially. Fresh water is a very poor conductor, but saline and acid solutions are relatively good ones. As between fresh and salt water, the differences lie chiefly in the degree of saltness and the amount of contained air. Increased concentration increases the conductivity but reduces the power of the water to absorb air, and the corrosive effect depends on the proportion of contained air as well as on the conductivity of the solution. The fresher the water the greater the amount of contained air.

Copper, and its alloys with tin, zinc and lead, set up very injurious galvanic action with iron or steel. The oxides of iron are all electrically negative to iron and steel in saline and acid solutions, forming couples with the metal which waste it. The strength of the couple formed with the oxide, and the consequent rate of corrosion, is least with the ferrous and greatest with the magnetic oxide, the latter being practically as negative to iron as copper. It has been proved by experiment that steel plates freed from mill scale, connected galvanically to plates which have not been so freed, set up an electric current capable of being measured by a galvanometer. This mill scale is found to be about as effective as copper in producing a current.

The product of galvanic corrosion is a mixture, in variable proportion, of the hydrated ferrous and ferric oxides accompanied by products of the decomposition of the liquid. The hydrogen evolved by electrolysis is at first dissolved by the liquid to saturation, and beyond that quantity is liberated.

INTERNAL CORROSION.

It may be concluded, from what has been said above, that the existence and progress of corrosion within a boiler depend upon the nature of the water used in it. If it were possible to use perfectly pure water from which all air had been expelled, and entirely pre-

vent the admission of air, carbonic acid, fatty acids in solution, or salt water, internal corrosion of the boiler could be practically prevented. But this is not possible. Some or all of these impurities become mixed with the feed water and enter the boilers in spite of all care taken to prevent it, and the efforts of those in charge must be exerted to reduce their quantity to the least possible amount and to neutralize, as far as possible, their action.

Air in water is the greatest and most active corrosive agent present in the boiler. In a series of carefully-conducted experiments on the corrosion of boiler tubes, extending over a period of nearly two years, Lieut. Commander W. F. Worthington, U. S. N., showed the potent effects of oxygen dissolved in the water on various kinds of tubes, as well as the effects of galvanic action and of free acids. The main tests were made by forcing varying quantities of air through the water in which specimen pieces of tubes were kept immersed. Remedies and preventives were also experimented on, and, as the results are particularly valuable, much of the information which follows has been taken from Mr. Worthington's paper, published in the *Journal of the American Society of Naval Engineers* in 1900 and 1901.

It has been estimated that a ton of water will absorb from three to four pounds of oxygen, depending upon the temperature and pressure conditions of the water. Stromeyer states that under a pressure of 150 pounds each ton of cold feed water will absord 3.2 pounds of oxygen. Assuming the most favorable conditions, that ferric oxide, Fe_2O_3, is formed by the union of the oxygen with the iron (the atomic weight of iron being 56 and of oxygen 16), then 3.2 pounds of oxygen will completely corrode

$$\frac{2 \times 56}{3 \times 16} \times 3.2 = 7.47, \text{ say } 7\tfrac{1}{2} \text{ pounds of steel.}$$

Upon this basis, in one of the "Castine's" boilers, for example, which holds 12 tons of fresh water, there would be present 38.4 pounds of oxygen, which would be able to corrode completely 90 pounds of steel. If we take the weight of an ordinary steel boiler tube, 2 inches in outside diameter and No. 13 B. W. G. (.095 inch) thick, to be .161 pound per inch of length, the weight of one tube, 7 feet 10 inches long, will be about 15.13 pounds. There would then be enough oxygen in this boiler to corrode completely nearly six of these tubes. If, instead of forming Fe_2O_3, FeO or Fe_3O_4 were

formed, the case would be worse. Owing to the loss of water from leaks about the boilers and elsewhere, a considerable quantity of

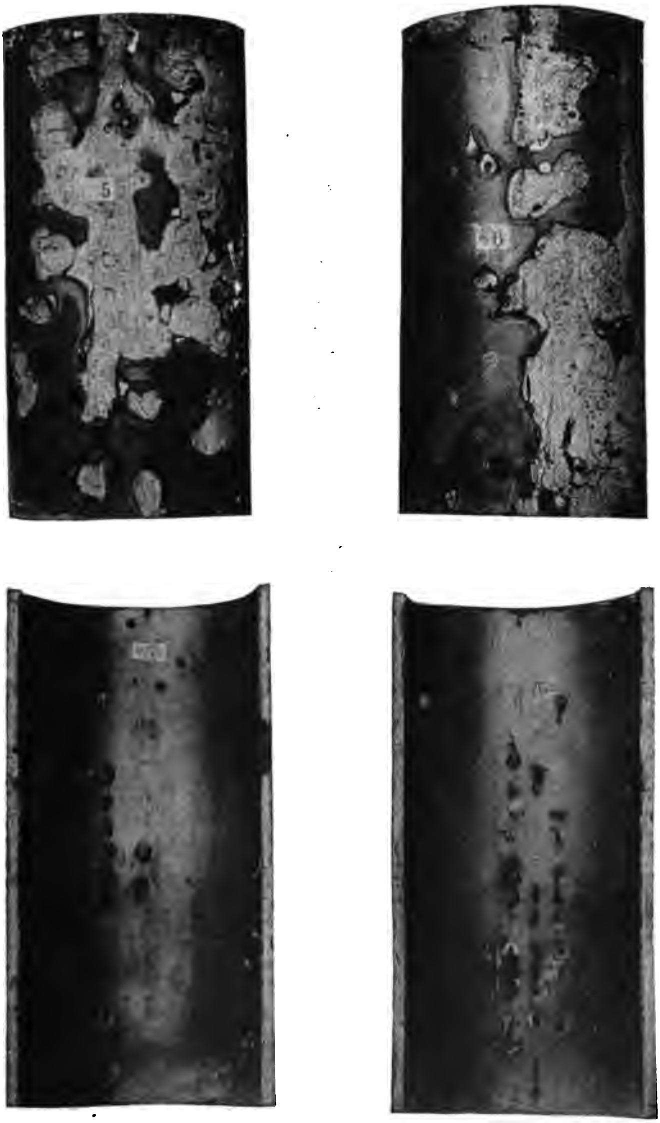


FIG. 12.

reserve feed water was required on this ship, as "make up," introducing additional oxygen and further increasing the destructive

effect. If salt water had been used as "make up," the damage would have been still greater, for additional reasons which will be explained further on.

This example will give an idea of the magnitude of the destructive effect of oxygen in combination with water. Naturally, the tubes are the first parts of the boiler to be destroyed by the effects of corrosion, these being the thinnest parts that are exposed to the action of the fire and gases on one side and water on the other. Figure 12 shows the effects of air in combination with water on two samples of seamless steel tubes. In this case the corrosion took the form of "pitting," especialy shown by the two spots above the numeral 6 in the figure and by the spot below it. These were particularly deep. Another point to be noticed is the appearance of the insides of the tubes, shown in the lower halves of the figure. These are the sides which were exposed to the direct action of the jets of air in the experiments, and the corrosion there was less than on the upper and convex side. In other experiments made by Mr. Worthington, the effect on different metals was shown, not even nickel steel (30% nickel) escaping, although this alloy was supposed to be very difficult to corrode.

The effects of corrosion are not always shown in the same way, but are rarely uniform over the whole surface of a plate. It is in the form of "pitting," or the formation of small deep pits, which finally pierce the plate, that its effects are most often seen and most seriously felt. Whether the localizing in spots is due to the irregular quality of the metal, as a result of the processes of manufacture, or other causes, is not yet known.

Again, corrosion is found unevenly distributed in the boiler. Sometimes the steam space is most attacked, and sometimes the bottom, dependent somewhat on the method of admitting the feed. The principal methods of feeding shell boilers in present practice are: 1. Admitted over the back end of the tubes and mixed with the hot water, thus promptly expelling the air. 2. Led through internal pipes until heated sufficiently to lose its air. 3. A combination of the two methods is generally used. With internal pipes, copper, brass and iron pipes are found extensively corroded, due to the air in the feed water.

Carbonic acid gas is always present in small quantity in the atmosphere and is taken into the boiler with the air in the feed water. It may also be produced by the oxidation of any organic

matter contained in the water. Its presence in the boiler materially aids corrosion. Very little is required, as this acid gas, as we have seen above, acts simply as a carrier of the oxygen and is not itself used up. This gas is contained in small quantity in sea water and in a larger and more variable one in river water, being absorbed from vegetable growths and animal matter. It is undoubtedly the active corrosive agent in certain river waters which are noted for their injurious effects on boiler tubes, such as the juniper water from the Dismal Swamp at Norfolk, Va., and the waters from one of the tributaries of the Parana river in South America, and from the mountain streams at Cape Town, South Africa.

The presence of organic matter in water may be detected by adding a little sulphuric acid, H_2SO_4, which will turn the water dark.

Protection against Air and Carbonic Acid Gas.—The admission of air and carbonic acid gas into the boilers cannot be entirely prevented, but can be reduced to a minimum by keeping the water in the boilers as long as possible without change; by promptly stopping all leaks, so that the amount of make-up feed will be reduced to a minimum; by careful attention to the feeding, so that the level in the feed tank is always sufficiently high to prevent the feed pump from drawing in air instead of water; by keeping the temperature of the water in the feed tank near the boiling point at all times, under way and in port, to expel air from the water, even if live steam must be used; and by permitting the free escape of air from the surface of the water in the feed tank and in the reservoir tank from the distillers. By keeping the water slightly alkaline at all times the corrosive effect of carbonic acid, or of other acids, if any are present or are formed, is neutralized. The following articles of the Navy Regulations (see Appendix) cover the subject of protection against air: Art. 1609, pars. 7, 9, 14, 15, 22, 23 and 29, and Art. 1621, par. 2.

Fatty acids in solution in boiler water was one of the first causes assigned to account for the corrosion of boilers when this became the subject of serious study and investigation. These acids resulted from the decomposition by heat of the animal and vegetable oils then plentifully used for the lubrication of such working parts as came in contact with the steam, such as the interiors of cylinders, valve chests and piston rods. These oils, being broken up in the cylinders by the high temperature of the steam, evolved fatty

acids which were discharged in a free state to the condenser, where they were taken up in the feed water and sent to the boilers. All danger from this source has now been removed by the exclusive use of mineral oils for internal lubrication. These are of hydrocarbon composition and contain no organic matter, and, therefore, cannot form injurious acids. The Regulations are now very explicit on this matter, as is shown by Art. 1606, pars. 5, 6, 7, and Art. 1609, par. 5.

While mineral oil is not a corrosive agent, it is the source of serious accidents to furnace crowns and also other heating surfaces when it is allowed to be deposited upon them. This oil is lighter than water, and if by leakage from the condenser, priming of the evaporators, or other causes, salt water is admitted to the boiler, the calcium sulphate of the sea water joins with the oil on the surface. The specific gravity of this mixture increases until it becomes the same as that of the water in the boiler, and is then carried about in the convection currents and widely distributed. This deposit is a poor conductor of heat. Because it is oily, it will not adhere closely to the plates, but, nevertheless, will prevent the water from coming in contact with them. Settling on the furnace crowns, the deposit is heated, gives off gas, and swells from $\frac{1}{64}$ to $\frac{1}{8}$ inch in thickness, becoming spongy and more non-conducting. When the furnace crown is hot enough to bulge or "come down," this amount of heat is sufficient to burn off the deposit, so that it is rarely found on subsequent examination of the plates. To prevent the entrance of oil into the boilers, the feed water is generally forced through a filter or grease extractor, which abstracts most of the oil. Other means of preventing this deposit are the frequent use of the surface blow, and the use of the purest mineral oil in the smallest possible quantity, as required by paragraphs 5 and 6, Art. 1606 of the Regulations.

Galvanic Action.—As fresh water is a very poor conductor of electricity, galvanic action in a boiler would not exist if it only were used. But owing to the leaks in the condenser and salt water being sometimes used for make-up feed, the possibility of the harmful effects of galvanic action, due to the presence of electrically different metals and the brackish water as a conductor, cannot be ignored. When internal brass feed pipes or other brass fittings are used, the galvanic couple formed with the iron or steel is almost as strong as when copper is used. The exciting action of the water increases with its acidity, concentration and temperature.

Protection against Galvanic Action.—It is evident that the best protection against galvanic action is the use of pure water, as its freedom from salt and acids will prevent harmful action from this source. Every effort should, therefore, be made to prevent the loss of fresh water through leaks, and the entrance of salt water by leaks or by priming of the evaporators. The water should be tested regularly to ascertain its condition as to acidity and concentration. Methods of testing the feed water are given under "Salinometers." As an additional measure of precaution, zinc protectors are fitted. Zinc is very strongly electro-positive to copper and brass and mildly so to iron and steel, and, when placed in an exciting fluid favorable for galvanic action, the theory is that it induces the corrosive agents to attack itself and leave the iron or steel uninjured. But whether the protection it affords is entirely of galvanic nature or partly chemical is not fully determined. Zincs that have been suspended in a boiler under steam for a few months, no attention being paid to make good electrical connections, very often become brittle with an earthy appearance. Chemical analysis shows that these zincs have been converted into oxide, and, therefore, a certain amount of oxygen must have been taken from the water and prevented from uniting with the steel of the boiler. If a ton of water contains 3.2 pounds of oxygen (the atomic weight of zinc being 65), $65 \times 3.2 \div 16 = 13$ pounds of zinc would be converted into zinc oxide.

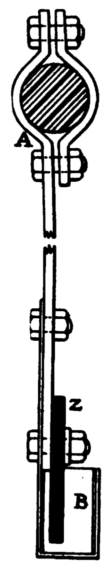


FIG. 13.

Art. 1606, par. 11, and Art. 1609, pars. 2, 3, 4, of the Regulations, prescribe the manner of using zinc protectors, and Fig. 13 shows one of the usual methods of securing the zinc slabs. The perforated basket or trough B is suspended below the slab to catch the pieces of zinc as disintegration proceeds. The surfaces between the zinc Z and the hanger A, and between A and the brace, stay or other part of the boiler, must be in good metallic contact always.

If after the zincs have been in use for some time, corrosion should be noticed at any place, the number of zincs near that place should be increased, and the location of the spot recorded in the log, as well as the additional measures taken to prevent its spread. A good protection to the corroded place, if not on a

heating surface, is given by a thin wash of cement put on after the metal has been scraped bright and cleaned with soda.

Use of Salt Water.—Besides the influence of salt water in promoting corrosion by introducing air and carbonic acid gas into the boiler, and serving as an exciting liquid favorable to galvanic action, as has been noticed, another cause of corrosion is ascribed to it in the liberation of hydrochloric acid by the decomposition by heat of the magnesium chloride contained in it.

Besides its corrosive influence, the use of salt water in large quantities results in the formation of heavy scale from the deposition of the salts in the water. This alone causes a big loss in evaporative power; the scale is very difficult to remove and has often caused dangerous overheating of plates and tubes. In tubulous boilers, especially in those with tubes that cannot be easily examined and cleaned, great care must be used to prevent deposits on the thin surfaces of the tubes, as these are under pressure, and a small accumulation will soon cause overheating and consequent explosion.

But it is not only salt water that causes deposits. Water from shore, or from rivers, often causes deposits from the lime in solution, or from sand or other impurities held in suspension. Fresh water that is not harmful to boilers, especially to tubulous boilers, is not merely water that is not sea water, but it must be chemically pure and hold no matter in suspension. Distilled water, which has been tested, fills these requirements and should, therefore, always be used. Owing to the above conditions, the use of pure fresh water in the boilers was shown to be a necessity and is now, whenever possible, obligatory, as shown by Art. 1609, pars. 13 and 15, of the Regulations.

Use of Alkalies.—The addition of an alkali, such as caustic soda, caustic potash and carbonate of soda, to the boiler water, in order to neutralize the destructive action of free acids which may be contained in it, has long been recommended and used. The action of soda on fatty acids, if these are present, is a process of saponification. Animal and vegetable oils are compounds of fatty acids, chiefly stearic, with glycerine, and when boiled in a solution of soda become decomposed, the former uniting with the soda to make a harmless soap, and the glycerine, also harmless, remaining free. This decomposition into acid and glycerine may take place under the influence of high temperature alone, as in the cylinders of an

engine, and then the free acid is carried along with the feed water and, when it encounters the soda in the boiler, the same harmless saponification takes place. The use of the caustic soda or potash will be more efficient when organic matter is present than that of the carbonate of soda.

The water in the boilers should be frequently tested with *red* litmus paper; if this turns blue, the water is sufficiently alkaline. It is not enough to use soda only when the water shows acidity by the litmus test, for oxygen and carbonic acid may be present in sufficient quantities to cause active corrosion and yet not be sufficient to affect blue litmus paper. Mr. Worthington's experiments showed that carbonate of soda (sal soda) stopped the corrosive effects of air in cold water, and led to the belief that the same effect will be produced in hot water. Therefore, enough of this soda should be used to keep the water in all boilers, whether in use or not, slightly alkaline. The exact quantity to be used cannot be laid down, but it will, of course, depend upon the amount of air entering the boiler, which will vary with the amount of feed water used. By testing the water with red litmus paper every day when under steam, the least amounts necessary will soon be obtained. So long as the litmus test shows alkalinity, the soda is effective. The soda is not volatilized, and unless lost by leakage or carried over to the engines with wet steam, the quantity in the boiler remains the same. The soda should be put in the feed water in small quantities at intervals, not all at once, as this may cause the boiler to foam. Carbonates and hydrates of soda form a sticky mass with mineral oil, and thus prevent the latter from acting as a lubricant. Art. 1609, par. 8, and Art. 1610, pars. 1 and 2, of the Regulations, refer to the use of alkalies.

EXTERNAL CORROSION.

The chief cause of the corrosion of external surfaces of a boiler is, as before, the presence of air and its carbonic acid gas and moisture in contact with the exposed parts.

The greater part of a fire room in which the boilers are under steam is always dry, and if there were no leaks about the boiler and if the bilges were kept reasonably dry, very little corrosion would take place. But small leaks take place at joints of the pressure parts and around manholes, and water allowed to accumulate in the bilge wets the exposed parts of the boiler bottom, supplying

the moisture necessary to cause corrosion. Unless such leaks are stopped, corrosion occurs, which if allowed to go on for a long time may result seriously. Fire rooms in which the boilers are not in use are more subject to the varying hygroscopic conditions of the outside atmosphere, and, therefore, hardly ever dry enough to prevent corrosion.

Another common cause, accountable for much deterioration, particularly about the lower parts of the boiler, is the formation of acids, principally sulphuric and hydrochloric, in wet ashes. In wetting down hot ashes with sea water, while cleaning a fire, these acids are liberated by heat from the salts contained in the water. Some proportion of these acids escapes with the steam which is also formed, attacking any metallic surfaces with which they come in contact, but a considerable quantity is absorbed in the water and remains mixed in the wet ashes. If these are allowed to get into the bilges or accumulate under or against the boiler front, or against a bulkhead, the metal will waste away rapidly.

Ashes and soot, if allowed to remain in the furnaces, combustion chambers, tubes and uptakes after fires are out, absorb moisture from the atmosphere and keep damp the surfaces with which they are in contact, thus causing corrosion.

Protection against External Corrosion.—The following rules should be carefully observed to prevent, as far as possible, external corrosion. Certain paragraphs of Art. 1609 of the Regulations, which give specific directions on this subject, are referred to in some cases.

All leaks about the boiler and in the steam and water pipes should be stopped as promptly as possible; and, as a precaution against the occurrence of leaks, all joints should be made as carefully as possible. All leaks, which cannot be stopped while the boiler is under steam, should be attended to at the first opportunity after the use of the boiler is discontinued, and in order that none may be overlooked, a careful inspection should be made shortly before letting fires die out, and all leaks, however small, recorded. Signs of leaks under the lagging, or clothing, of boilers should be carefully noted. If steam itself does not appear, the water condensed from it may show itself far below. The leak should be promptly traced to its source by removing as much of the lagging as necessary. Leaks under the covered parts give rise to extended corrosion by keeping the lagging and the plate it covers damp, and by rotting the material when felt is used.

The bilges should be kept dry (par. 16).

All external surfaces of the boiler should be kept as dry as possible, and free from scale and rust and contact with wet ashes, and, where accessible, well painted with metallic paint (pars. 7, 16, 22).

The furnaces, ash pans, combustion chambers and tubes should be carefully cleaned of soot and ashes, and brushed, when through with the boiler for steaming. All interior leaks which were not visible while the boiler was under steam should be stopped.

Light fires should occasionally be made in drying stoves placed in the ash pits of boilers not in use, in order to dispel moisture from the interior fire parts (par. 24).

The uptakes should be kept free of dirt and well painted, and the air space between the uptake and casing of the boiler kept free of soot or coal dust (pars. 19, 30).

The sheet iron guards, generally fitted to the fronts of shell boilers around the lower parts of furnaces, should be kept free of rust and scale and well painted.

Ashes should not be retained in the fire rooms longer than necessary, and should never be stowed against any part of the boilers or bulkheads; boards or heavy canvas must be used to protect the metal surfaces (par. 32).

OTHER CAUSES OF DETERIORATION.

Besides the deterioration due to corrosion, there are certain other causes which shorten the life of boilers, the effects of which are generally more sudden and more noticeable. Warships on ordinary service steam at slow speeds, requiring the use of only a portion of their boilers at any one time, and the irregular nature of their employment and the frequent periods of inaction, due to the varying requirements of the service, subject the boilers to unequal working and violent changes. The consequent repeated expansion and contraction is more trying to boilers than the steady and continuous steaming usual in the ships of the mercantile marine.

It must also be remembered that naval boilers are not as well fitted to withstand violent changes as are those of merchant ships, owing to the reduction in their weight and size demanded by modern warship construction.

Frequent changes of temperature, and especially sudden changes, should be avoided. The more regular the working of the boiler

and the more gradual the necessary changes of temperature, the longer will be the life of the boiler. Sudden changes of temperature set up severe local strains which damage the boiler and cause leaks which are often serious.

Most of the conditions which may cause damage by sudden changes of temperature or by undue strains from other causes may be anticipated and avoided in the management of the boilers, and will be briefly noted, reference being made to certain paragraphs of the Regulations upon this subject. Although these remarks are particularly applicable to shell boilers, they hold for tubulous boilers as well.

When circumstances will permit, at least six hours should be occupied in raising steam from cold water in shell boilers (Art. 1609, par. 17); and, after discontinuing steaming, fires should not be hauled, but allowed to burn down and die out in the furnaces, with the dampers, furnaces and ash pits closed, thus permitting them to cool slowly and gradually. The boilers should not be blown down, but should be pumped out after the water is sufficiently cooled, if it is required to empty them (Art. 1609, par. 2). Connection doors must not be used as dampers (Art. 1609, par. 18). Any considerable increase in the speed of a vessel fitted with shell boilers should be obtained by increasing the number of boilers in use, under natural draft, until the entire number on board is in use, if requisite, and forced draft should not be used except in emergencies and during the specified power trials (Art. 1609, pars. 26, 27). Heavy banked fires should never be kept, except in emergencies, but when so banked, ash pan doors must not be put in place (Art. 1611). When coming to anchor or to a stop with heavy fires, sufficient notice, from half an hour to an hour if possible, should always be given to the engine room, so that fires may be allowed to burn down enough to be under easy control, and not make necessary the sudden checking of the overproduction of steam by violent means, which always cause trouble and sometimes serious injury.

OVERHAULING BOILERS.

The cleaning of the outsides of boilers, including all fire parts, is a matter of routine carried out as explained in Chapter II, and so soon as they are sufficiently cooled after each steaming. The cleaning of the inside of all accessible parts is the same in principle for both shell and tubulous boilers, and, although the differences of

construction require, in some particulars, different means to be employed, the subject will be understood from the following procedure for a shell boiler.

All leaky tube ends, seams, stays, rivets, etc., are noted, the plates in their vicinity cleaned, and their location marked with chalk. If the boiler has been in use for a long time and the length of stay in port will permit, the boiler should be opened and thoroughly cleaned inside. If the water is fresh and clean it is run down into the reserve tanks and saved, otherwise it is pumped overboard, The top manhole plates should be taken off before the boiler is run down, and the other plates so soon as the water is below them. It is important to do this in order that the boiler may be aired and the men started at scraping off the deposit before it has time to dry, as it is then much more difficult to remove. The boiler must be thoroughly aired before any one is allowed to enter. Accumulations of hydrogen have caused explosions, and there is danger of men being overcome through want of respirable air. The stop valves must be closed and securely lashed, or the wheels removed from their stems, and the feed valves secured, to prevent accidental opening while the men are working inside. All water that cannot be pumped out, or run down into the reserve tanks, should be drained into the bilge. Stop with wooden plugs the openings of all pipes in the lower parts of the boiler, in order that they may not become choked with scale or dirt. If fresh water only has been used, the boiler will require most attention around the water line and on the under sides of the furnaces, where a soft, oily deposit is to be found. If salt water has been used, any scale deposited on the heating surfaces must be removed, the tube sheets, tubes, combustion chamber tops and furnace crowns requiring the greatest attention. These deposits are removed by means of scrapers and scaling hammers, the confined spaces being cleaned and scraped by means of long thin scrapers and long bars with chisel-pointed ends. Care must be used with scaling hammers and bars that the surface of the metal to be scaled is not cut or nicked by the sharp edges and points. Small men must be selected for working in the confined spaces between tube nests, and above and below the furnaces accessible through the lower manholes. Deposits of salt scale around the tube ends, where they enter the tube sheets, must be removed, as they promote leaking, particularly about the combustion chamber ends.

The openings in the dry pipe, and those of the test cocks, gage glasses and steam gages are cleared. While this work is going on inside, the boilermaker proceeds to expand the leaky tubes, calk the leaky seams, rivets, etc., and test with a wrench the nuts of the screw stays in the combustion chambers. Glands of feed valves, test cocks, etc., should be repacked and new joints made as required. Valves which are rarely used should be moved, and those, which from some peculiarity of their position are liable to collect deposits of dirt, should receive special attention. The manhole plates are overhauled and made ready to put on again, using the same gasket, if good.

After scaling and before washing out is the time to make any repairs that may be necessary inside. The zincs must be examined and the thin ones renewed, baskets cleaned, and the hangers examined and a metallic contact made, if necessary. The dry pipe, the internal feed and blow pipes, and the circulating plates and their supports are examined to see if they are in good order and firmly secured.

When the work inside is finished, haul out the refuse from the bottom and wash out the boiler with the fire hose, using it first in the top of the boiler through the upper manhole, then over the furnaces, and finally in the bottom through the lower manholes. After all of the loose dirt has been removed, let the remaining water drain out through the drain cock. Finally, remove the wooden plugs which were put into pipes, replace the manhole plates, remove the lashings from the stop and feed valves, and pump up the boiler.

Sometimes parts of the interior are not accessible for cleaning, as in some shell, tubulous, and small launch boilers, and in such cases the cleaning is completed by putting enough soda into the water to make a strong solution, and boiling this by raising steam. This loosens the deposits, and then the fires are allowed to die out, the boiler blown down and finally pumped out. This method and that in which kerosene is used are more fully explained under tubulous boilers.

The cleaning and washing of the bilges, sending up ashes and dirt, wiping up floor plates, renewing paint where necessary, and cleaning paint and brightwork conclude the overhauling. The furnaces should not be primed until just before lighting fires.

EXAMINATIONS AND TESTS OF BOILERS IN SERVICE.

In order to ascertain the condition as regards the safety and tightness of boilers, after the vessel has been commissioned, and to determine the character and extent of any deterioration which may have taken place, periodical examinations and tests are required to be made. The Regulations, Art. 1612-1615 and 1620, pars. 8 and 9, require that boilers shall be thoroughly examined at regular intervals of about three months, besides at such other times as opportunity offers or when found necessary, and also that tests be made by water pressure and drilling when deemed necessary or advisable by the senior engineer officer.

Inspection.—These examinations are made by an officer, usually each time that a boiler is cleaned, and consist of a critical inspection of the condition of all accessible parts. All heating surfaces on both sides must be specially examined to determine their cleanliness and to detect possible corrosion, as well as the surfaces of the shell or drum around the water line. The stays must be calipered and their least diameters recorded, if any reduction by corrosion is detected. The condition of the zincs, internal pipes, openings in dry pipes and all openings in the shell or drums should be determined. The boilermaker should call attention to any serious leaks before he begins work on them, in order that their condition may be examined and any special defects or structural weakness detected.

A detailed description of the condition of each boiler at each inspection must be entered in the steam log and in the senior engineer officer's remark book.

Water Pressure Test.—The water pressure test, while it may be used to determine the tightness of a particular part of a boiler that has been under repair, as the renewal of tubes, replacing of stays, etc., is seldom necessary as a routine safety test until the boiler has been in service for two years, but after that should be repeated at regular intervals of about six months. The pressure to be applied is limited by the Regulations to twenty-five per cent more than the designed working pressure of the boiler which has been in service longer than two years.

The test is carried out in the following manner:

The safety valves must be secured on their seats by clamps on their stems, these being usually provided for this purpose and kept in the storeroom. The boiler stop valves must be shut tightly so

that they will not leak under the pressure. Whenever it can be done, steam should be shut off the section of pipe leading from the boiler, by closing the first bulkhead or other intermediate valve beyond the boiler stop valve; by draining this section and leaving the drains open, the occurrence of a water hammer and possible bursting of a pipe, in case the boiler stop valves leak under the test pressure, will be prevented. The feed valves not used for the test and the valves at top and bottom of the water gages must be closed. Pump the boiler full, leaving the air cock open until water is discharged through it. The pressure is usually applied by the regular feed pumps, their relief valves being set down; if these are not available, a large hand pump fitted to the feed pipe is used. During the application of the pressure, which should be increased gradually, the boiler should be carefully examined in all parts for leaks, and gages used to detect any change of form of shell, furnaces and combustion chambers. If the deflections shown by the gages become abnormal, the pressure should be released by opening the bottom blow valve or drain cock slightly to ascertain if there is any permanent set. The pressure should then be slowly increased and frequently removed to ascertain that the safe limit is not passed.

The following particulars of the results of this test must be recorded: The greatest pressure applied; the load per square inch on safety valves previous to the test and when boilers were first used; the date of last repair; the length of service for which the boilers were repaired; the effect of the test on the plates and stays of the furnaces, combustion chambers, shell, and tube sheets; the estimated durability of the boilers with such repairs as can be made by the force on board; and such additional information as may be considered necessary to enable a complete estimate to be formed on the condition of the boilers.

Drill Test.—This is not generally necessary until a boiler has been in service for three or four years, but after that may be required at intervals of from eighteen months to two years. The test is carried out by drilling holes, not over one-half inch in diameter, through the plates at certain places. After the holes are drilled, the burrs must be carefully removed from both sides, and the thickness of the plates measured and compared with the original. These holes are afterwards tapped, and plugs screwed in and securely riveted over so that no leakage shall occur. If unexpected

wear be discovered on drilling, the plates should, if accessible, be examined on both sides in the vicinity of the thin part, and other holes should be drilled in suitable places, in order to ascertain if the deterioration is local or general. The parts which may need drilling are the shell at the water line and sometimes the steam spaces, furnaces at the crown and at the level of the grate bars, combustion chambers, and the tube sheets in shell boilers, and the steam and water drums and the downtakes in tubulous boilers.

The thickness of the plates originally and when drill-tested, the probable cause of corrosion or wear, and all other details of the test will be recorded, with sketches showing the position of the holes drilled at each test.

PRESERVATION OF BOILERS IN "ORDINARY."

Besides the means of preserving boilers already given, the following additional ones are adopted when a ship is placed out of commission and is laid up in "ordinary," the boilers then lying idle for a long period (see Regulations, Art. 1727, par. 7).

During the season when no liability to freezing exists, the boilers are kept entirely filled with fresh water rendered alkaline by the addition of carbonate of soda (sal soda), the water during the filling having been heated, if possible, to expel the air. After using this method, the boilers must be emptied and washed out before steam is raised. On the approach of cold weather, the boilers are pumped out and thoroughly dried by a drying stove placed in front of a lower manhole, after removing this lower and an upper manhole plate. An open box containing unslaked lime is then inserted through each manhole, the box being of the greatest capacity possible, and filled to about half its height. The boiler is then closed tight, all valves on it having been closed previously. Joints in the feed and blow pipes are broken, so that no ingress of water is possible during the time the boiler is closed in this way. In addition to the unslaked lime, which will absorb the moisture, a pan of charcoal, to burn the oxygen in the air contained in the boiler, is sometimes put in.

GENERAL CONCLUSIONS.

1. Allow as little air as possible to get into boilers. 2. Use pure fresh or distilled water only and keep it slightly alkaline at all times. 3. Keep boilers not in use filled. 4. Keep a sufficient

number of zincs in good metallic contact and in good condition. 5. Avoid all sudden changes of temperature. 6. Keep the internal surfaces clean, especially the heating surfaces, and more particularly the tubes of tubulous boilers. 7. Keep the external surfaces clean, dry and well painted, wherever possible. 8. Take an intelligent interest in what goes on in the fire room, and make the care of the boilers the first consideration at all times.

CHAPTER IX.

BOILER FITTINGS AND APPURTENANCES.

The various fittings on and appurtenances of the boiler, by means of which the steam supply is regulated and continued and the boiler safely managed, will now be taken up in detail.

In order to perform these functions, each boiler must be fitted with: 1. A *stop valve,* to regulate, or shut off altogether, the exit of steam from the boiler to the steam pipes which connect it with the engines. 2. A *safety valve,* by means of which any dangerous increase above the safe working pressure in the boiler will be relieved automatically. 3. One or more *steam gages,* to show the pressure in the boiler. 4. Two or more glass or mica *water gages* and several *gage cocks,* by means of which the height of the water in the boiler is made visible. 5. One or more *feed check and stop valves,* through which the water in the boiler, as evaporation and drawing-off of steam proceed, can be replenished or *fed.* 6. One *surface blow valve,* through which oil and scum, which may get into the boiler with the feed water, can be blown overboard. 7. One or more *bottom blow valves,* through which mud or other heavy impurities, which may be deposited at the bottom of the boiler, can be blown overboard.

Besides these necessary fittings, there are others which are added to special boilers or for convenience.

Under appurtenances may be classed the manholes and their plates, the uptakes, smoke pipes, ventilators, ash hoists and ash ejectors.

Feed Check Valves.—Each boiler has two of these valves, entirely separate from each other, one connecting the boiler to the *main feed pipe,* and, therefore, called the *main check valve,* and the other, to the *auxiliary feed pipe,* and called the *auxiliary check valve.* Two valves are always provided, except for steamboats, for safety, in case one of the feed systems should fail to work.

Fig. 14 shows one form of check valve. Between this valve and the boiler there is a globe stop valve bolted to flange O, by

means of which communication with the boiler can be shut off, thus allowing the check valve to be overhauled, if necessary, when steam is on the boiler.

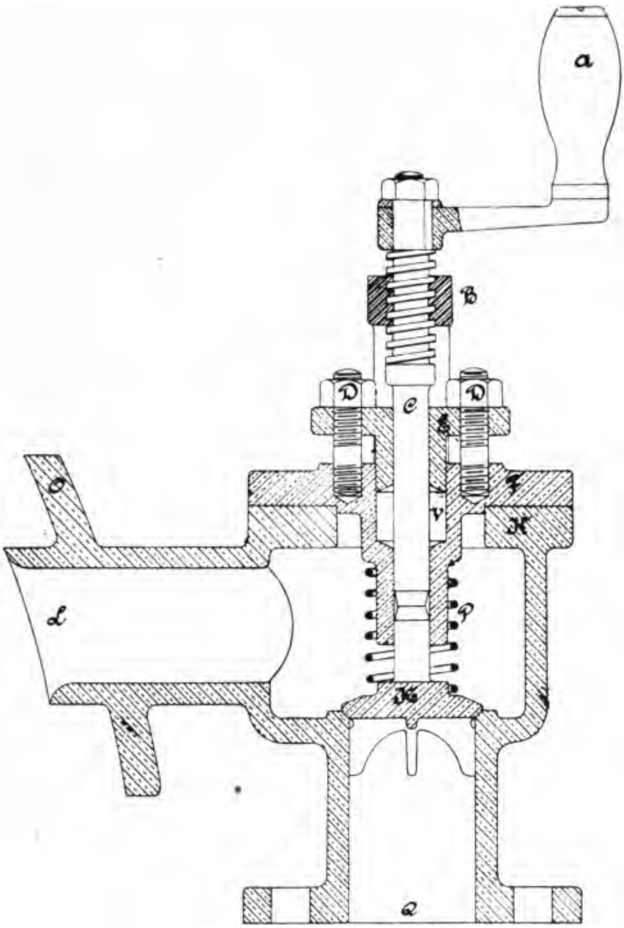


FIG. 14.

The check valve consists of the composition chamber H, with inlet for the feed water at Q and outlet through the nozzle at L. The valve K can move up and down freely, the amount of movement or *opening* being regulated by the valve stem C and handle A. In the figure, the stem is shown screwed down to close the valve entirely. The valve is guided below by the wings and above

by the short cylindrical projection, this being separate from the stem C. The phosphor bronze spring P helps to close the valve when feeding.

When steam is on the boiler, the stop valve next to O is kept open, and the boiler pressure will then be on the back of valve K and keep it shut. When the boiler is to be fed, A is turned slightly, thus raising the bottom of C a certain distance and leaving a space between it and the top of the projection on K. The valve can now lift through that distance whenever the pressure below it in the feed pipe is greater than that on the back. This will happen during the early part of the stroke of the feed pump; towards the end of the stroke, as the pressure decreases, the valve will be forced down by the steam pressure and spring. This alternate opening and closing of the valve with the strokes of the pump produces an audible click. If this is not heard, the check valve is not working properly and should be examined. Should the feed pipe near the valve chamber be very much hotter than the rest of the pipe, it is evident that the check valve leaks. Small holes are drilled in the guide for the valve stem and projection on K for the escape of water above the latter as the valve lifts.

An internal pipe is fitted to each feed valve on all shell boilers, and generally on tubulous boilers, to direct the incoming water. In shell boilers, the main feed pipe usually runs above the tubes and points downward in the spaces between the nests of tubes, and between the shell and the adjacent nest of tubes on one side, the auxiliary pipe running in a similar manner on the other side of the boiler.

In tubulous boilers, the feed check and stop valves are on the steam drum, and, owing to the height of these drums above the fire room floor, gear for working the valves from the floor plates is provided.

The bottom of the outlet nozzle is always at least ½ inch above the seat of K, to ensure a water seal on top of the valve. The stems of both check and stop valves, like all other valves on boilers, have screw threads outside of the valve chamber.

In order that the amount of feed water supplied can be regulated for each boiler separately, without varying the speed of the feed pump, the latter is fitted with a relief valve.

Feed Check Valve for Steamboats.—Fig. 15 shows an outside view and a section of a simple form of check valve which is some-

times fitted to the feed pipe of steamboat boilers. It is also frequently used in drain pipes to prevent the return of the water.

The valve swings on a pin, which can be removed by unscrewing a plug in the side of the chamber. As will be noticed, the valve will open only to let in water from the left, into which end is screwed the discharge pipe of the feed pump. The right hand end is screwed on a nipple in the boiler, and the back of the valve is held down by the boiler pressure.

When the valve is to be examined, the top cap is unscrewed. Should the valve leak, it can be ground and fitted to its seat by inserting a screw driver through the inclined hole on the upper side, after removing the plug there.

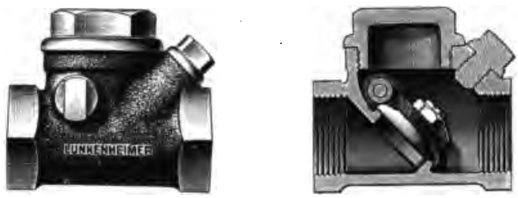


FIG. 15.

Automatic Feed Regulators.—In nearly all types of tubulous boilers, owing to the comparatively small quantity of water contained in them, some kind of apparatus, which will regulate the supply of feed water automatically, is fitted. With the Belleville boiler, which is not used in our Navy, but largely used in European navies, this feed regulator with its pump is an absolute necessity. Of the tubulous boilers used in our Navy, nearly all, except the Babcock and Wilcox and the Ward boilers, are designed to be fitted with regulators, but these are not always used.

Fig. 16 shows the various parts of the Thornycroft regulator. This is fitted to the Yarrow boilers of the "Nashville" and to Thornycroft boilers. By referring to Plate VIII, the details of Fig. 16 will be more readily understood.

Fig. 16, 1 shows a vertical section of part of the steam drum, Fig. 16, 3, a horizontal section, and Fig. 16, 2, a front elevation, with the left half in section. The regulator consists of a lever balanced near the middle, with a float at one end (the right hand end in the figure) and a counterbalance weight at the other, the whole supported, through the bell crank lever, Fig. 16, 4, by the frame shown in section in Figs. 16, 4 and 5. This frame contains

also a feed valve chamber, with inlet for the feed on the right, Fig. 16, 5, and a double poppet valve, shown in place in Fig. 16, 4. The lever is connected to the valve above by a ball and socket joint link, Fig. 16, 4. The feed check valve is shown on the right of the drum, Fig. 16, 2, the feed entering the valve chamber in the frame through the curved pipe (the lower one in Fig. 16, 3) and being discharged into the drum through the T-shaped pipe.

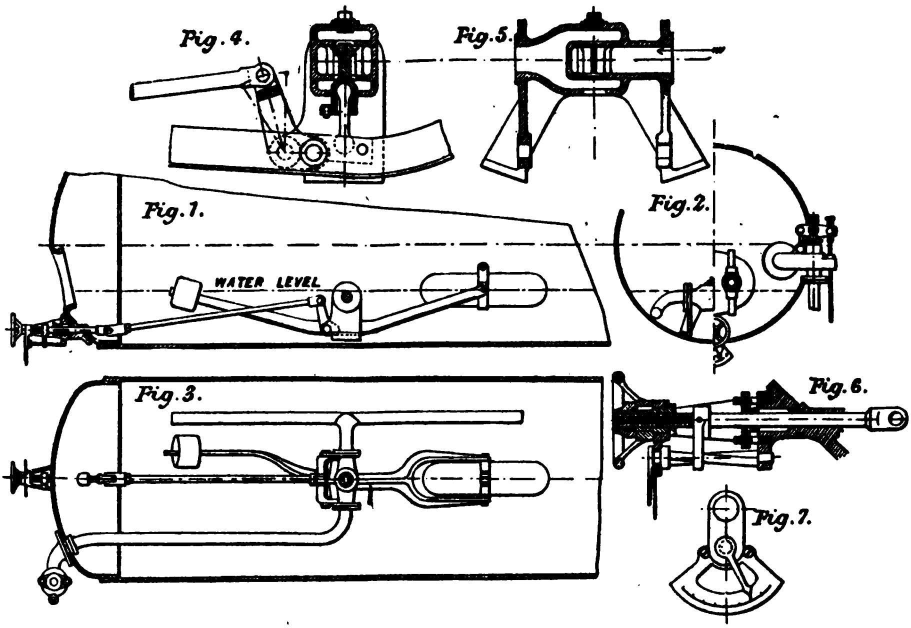


FIG. 16.

The supports for the bell crank lever are shown by the dotted circles, Fig. 16, 4, and the fulcrum of the float, by the solid circles. The upper end of the bell crank lever is connected by a rod, Fig. 16, 1, to a stem, which, passing through a stuffing box in the head of the drum, can be moved in and out by the adjusting screw wheel. The details of this are shown in Fig. 16, 6. An arm fixed to the stem works a spiral at its lower end and thus turns the pointer in the indicator, Fig. 16, 7.

By means of the adjusting gear, and the bell crank lever inside, the fulcrum of the float lever can be raised or lowered, and, therefore, the valve given a greater or smaller opening without affect-

ing the position of the float. The position of the latter will depend upon the water level in the drum, rising or falling with it.

The water level in several boilers fed from the same pump can thus be kept practically constant, after the speed of the pump and the opening of the feed check valve have been regulated, slight irregularities in the evaporation of the separate boilers being adjusted by the gear on each drum. The main use of the adjusting gear is that of regulating the valve opening for different rates of evaporation, so that too great a range of movement of the float will not be required. More water is, of course, needed in a given time when the boiler is forced than when steaming easily. If the fulcrum of the float lever were not movable vertically, the opening of the valve would be changed by the float, or the water level only, and, therefore, when the greatest opening is required, as under forced draft, the water level would be the lowest.

The double poppet valve, which is simply a casting with two valve faces, instead of the usual single one, is made to open downward, so that, in case of accident, the valve will drop down and remain open. As it is not a *stop* valve, but a regulating valve only, it is, therefore, never quite closed. When not steaming, the feed stop valve on the boiler must be closed. In order that the whole apparatus need not be made too large, a certain excess pressure in the feed pipe over that in the drum is required. This excess varies for different ships, say from 40 to 50 pounds, the latter being usual on torpedo boats and destroyers.

Water Gages.—These are fitted at the front, or, more generally, at the sides, of each shell boiler, and on the side or head of each steam drum in tubulous boilers. Double-ended shell boilers have two of these gages at the feeding end, placed as far apart as possible, and one at the other end. Fig. 17 shows a glass water gage without the wire mesh guard, which is now usually fitted around the glass inside of the four guard rods. All water gages must be automatic or self-closing.

The gage consists of an annealed glass tube, secured by stuffing boxes to the top and bottom *shut-off* cock or valve chambers, the *blow-out* cock or valve at the bottom, and an automatic self-closing valve in the back of each sut-off chamber. On tubulous boilers, the whole gage is connected directly to the nozzles on the steam drum, the shut-off valves being then frequently placed back of the self-closing valve, as in Plate X. On shell boilers, the chambers

are connected by pipes to the top and to near the bottom of the boiler, respectively, as in Plate I, each pipe having a stop valve on the boiler shell; the shut-off valves are then as shown in Fig. 17. From the blow-out cock or valve, a drain pipe leads down to the bilge.

The glass is $\frac{3}{4}$ inch in outside diameter for all large boilers, and $\frac{5}{8}$ inch for small boilers, the exposed length varying from 10 to 16 inches, and the whole length, from 2 to $2\frac{1}{2}$ inches more. One or two rubber rings, or grommets, around the glass near each end, set up by a washer and nut on each stuffing box, make steam and water-tight joints. This is shown clearly in Fig. 20.

To prevent scalding of the firemen when a gage glass breaks, automatic self-closing valves are fitted. These consist, as shown in Figs. 17, 18, and 19, of either a small valve or ball, which is free to move within a chamber through which the steam or water passes from the boiler to the glass. So long as there is equilibrium of pressure within the water gage, this automatic valve does not move. But, if the glass breaks, there will be a rush of steam and hot water into the fire room, and, owing to the lower pressure on the opposite side, the valve will be forced against the seat provided. The amount of steam and water blown out will thus be very small, and the shut-off cocks or valves can be closed by hand without danger of scalding. A new glass can then be put in by slacking back the stuffing-box nuts. To catch any small pieces of glass, in case of breakage, a wire mesh guard is usually fitted around the glass.

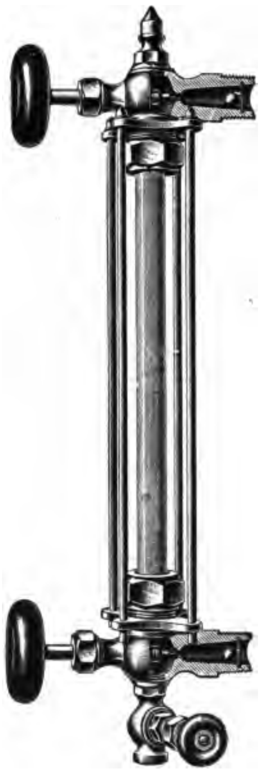


FIG. 17.

Fig. 17 shows the Star, and Fig. 18, the Crosby "ball" valves, and Fig. 19, a Keyser valve. The automatic valves are all shown open; the shut-off valves of the first two are open and those of the Keyser closed. It will be seen that there is a seat for the automatic valve and another one, opposite this, for the shut-off valve. A light spring in the Keyser gage keeps the automatic

valve away from the seat under ordinary circumstances; the back or boiler side of this valve has passages cut out of it, through which the steam or water enters the shut-off chamber when the valve is open. The prongs which hold the ball in the Crosby gage are very light, so that it will not take much pressure to force the ball towards its seat. The ball in the Star gage rolls down the slightly conical surface when in equilibrium. The stem of each

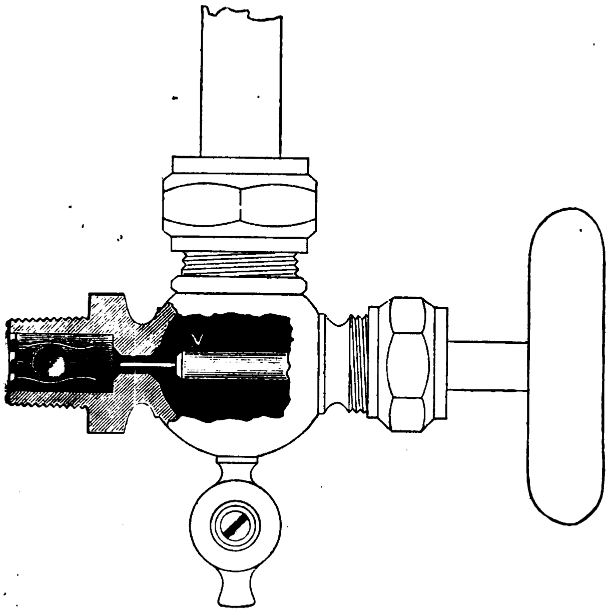


FIG. 18.

shut-off valve ends in a pin projecting beyond its seat, by means of which the automatic valve is pushed back to its normal position as the shut-off valve is closed. When the glass has been renewed, the shut-off valves are opened, and the automatic valves remain in place and leave the passage for steam or water open.

Where the water gages are too high above the fire room floor to be within easy reach, the wooden wheels are replaced by grooved metal ones, with knurled or milled surfaces, which are worked from below by a continuous chain. Similarly, when cocks are fitted, they are worked by levers and rods, the latter hanging down to within easy reach.

Mica Gages.—In addition to the glass gages, high pressure boil-

ers, such as tubulous boilers, are fitted with mica gages, in which the gage glass is replaced by a metal casting which has a long narrow opening in it covered by mica. In all other respects the gage is the same. Glass does not stand the high temperature well, while mica is not affected.

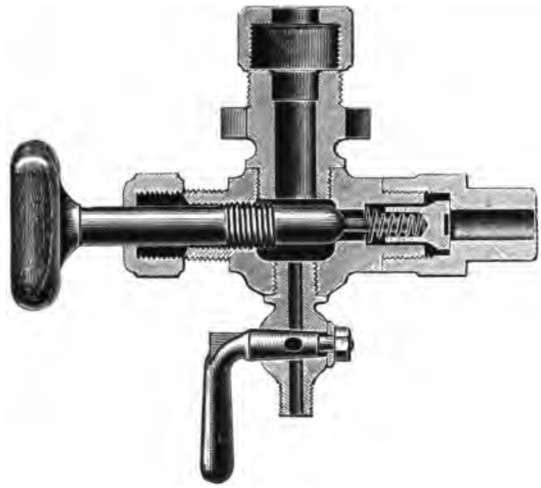


FIG. 19.

In Fig. 20, B shows the outside of this casting, which is secured to the shut-off chambers by stuffing boxes and rubber grommets. The sectional view shows clearly how the narrow sheets of mica M are held in place by the composition plates A and through bolts. Fiber washers are put between the mica and plates to make a tight joint, as the mica is too brittle for that purpose.

Location of Water Gages.—The gage glass must be so placed that the water tender may know that there is a safe amount in the boiler, so long as the water shows in the glass, and the glass must be long enough to show the level under all ordinary variations.

On shell boilers, the gage is placed at such height that the lowest exposed part of the glass is at least one inch above the highest heating surface. The top of the combustion chamber is now usually shown by an index plate fixed close to the water gage. The working water level is usually from 6 to 8 inches above the bottom of the exposed glass. On tubulous boilers, the gages are so fitted that the middle of the length of the glass is either below or at the center line of the drum.

Sometimes, instead of connecting the gages direct by pipes with the top and bottom of a shell boiler, they are connected to a *stand pipe,* as is the English-built "Albany" and "New Orleans." This stand pipe is a hollow casting consisting of a vertical part with two horizontal legs. The latter are connected direct to the boiler shell, without valves, the center of each opening in the shell and the corresponding shut-off cock of the gage being very nearly in the same horizontal plane. The column of water in the stand pipe, being outside of the boiler, and between it and the gage, is less exposed to the effects of rapid ebullition than the water inside of the boiler, and the water in the gage will, therefore, give more reliable indications than if the gage were attached directly to the boiler shell. The openings of the stand pipe are, however, too near the working level of the water, and any oily scum carried up with the steam from the water surface will be more liable to get into and dirty the glass than if the gage were connected direct to the top of the boiler. Similarly, when the boiler is forced much, the effects of the violent boiling of the water extend down to near the lower opening and thus cause unsteady indications in the gage. When the lower part of the gage is connected to the bottom of the boiler, where the water remains almost quiet under all rates of steaming, no such unsteadiness can occur. The method used in our Navy is, therefore, much more preferable.

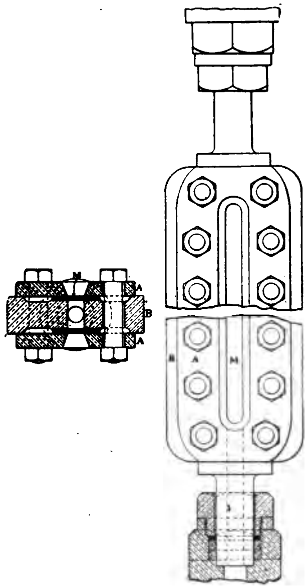


FIG. 20.

Effect of List on Boilers.—When a ship fitted with shell boilers is injured in action or by accident, so that she has a *permanent* list, great care must be used to ascertain the proper working level for the altered position of the water in the boilers with reference to the highest heating surface. As stated before, double-ended shell boilers have two water gages at one end and another at the other end. Single-ended shell boilers, placed fore-and-aft, have

only two gages, both at the same end; when placed athwartship, another gage is usually fitted at the back end.

Take the case of the shell boilers placed fore-and-aft and a list to port. So long as the list is small enough, so that water shows in the starboard gage, no heating surface is uncovered. But, if the starboard gage is empty, the port one, which will probably be quite full, cannot be used to indicate the water level. The starboard gage must then be depended on, after the boilers have been pumped up to bring the water in sight in that gage. In the same way, with shell boilers placed athwartship, the gage at the end showing the lower level must be used.

If the ship is down by the head or stern, boilers placed athwartship will show comparatively little difference in level between the two front gages. If the boilers are fore-and-aft, the matter becomes more serious, especially with double-ended boilers. As before, so long as one of the end gages, the one showing the lower level, can be depended on, the boiler may be worked with safety. But, if there are front gages only, and these are full at the lowest safe working level, it will be unsafe to keep steam on the boilers.

It will be noticed that the above explanations apply only when the ship has a permanent list. The ordinary changing of water level, as the ship rolls, requires no special attention, as the heating surfaces, even when uncovered by a deep roll, remain so for a short time only and are kept damp by the splash of the water.

With tubulous boilers placed fore-and-aft, as they are generally, no trouble from the listing of the ship is likely. When placed athwartship, the circulation may be interfered with in some types having inclined tubes, if the list toward the high ends of the tubes is equal to or greater than the angle of inclination of the tubes.

Gage Cocks.—In addition to the glass and mica water gages, each boiler or steam drum is fitted with several *gage cocks*, each attached independently and directly. In double-ended boilers, each end is fitted with these cocks. They are spaced equally in a vertical direction, about 6 inches in shell and 3 inches in tubulous boilers, the lowest one being about four inches *below* the highest heating surface in shell boilers. By opening each cock in succession, an experienced man can tell, from the steam or water blowing out, approximately where the water level is and thus check the indications of the glass gages. These cocks are

fitted with levers and rods, where necessary, to work them from the fire room floor, and with a drip pan and a drain pipe leading to bilge. See G C in Plates I and II.

Fig. 21 shows the standard pattern used in our Navy. A is a composition valve chamber which is screwed into the boiler or drum by the gas pipe thread S. The valve V and its spindle D and guide C are turned from one piece of rolled manganese bronze or Tobin's metal. The guide C is triangular in section, and the spindle D, circular where it passes through the movable seat B, and square at the end T. The valve has two faces. The inner seat for the valve is formed in the casting A, and the outer one in the block B, which can be screwed in and out by the handle H.

The valve is closed by screwing in the movable seat, and is opened by the steam pressure when the seat is screwed out. The

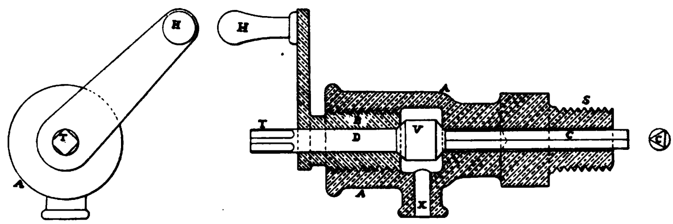


FIG. 21.

opening of the valve is at least $\frac{3}{8}$ inch in diameter, and that for the discharge at X, at least $\frac{1}{4}$ inch. By means of a wrench at T, the valve can be turned and thus the passage around C kept clear. The movable seat serves the same purpose as a stuffing box, but in a more efficient and safer manner.

Trying Gage Glasses and Cocks.—In order to make sure that the indication of the gage glass is correct and to clear the glass and connecting pipes of oil or obstructions, the gage is tried frequently during a watch. The whole glass and upper pipe are blown through by closing the lower shut-off valve and opening the blow-out cock. Then, by closing the upper valve and opening the blow-out cock, the lower passage will be cleared. After these trials have been made, the water in the glass will resume its level quickly, if the glass is in working order. The gage cocks are then tried, and, if these indicate a serious difference, the glass must be blown through again. It often happens that a piece of scale or other matter closes the opening in the lower pipe. In

this case, the indication of the glass would be altogether unreliable, and, if the opening be not promptly cleared, would become dangerously misleading by the rapid increase in level due to condensation of steam from above. If the top shut-off valve or the upper valve on a boiler under steam were closed, the gage glass would show full, as there would be no pressure on the water in the glass.

If, after blowing through several times, the glass does not work properly, the whole gage must be shut off by closing the stop valves on the boiler, the glass drained, and then the shut-off valves taken off. The automatic valve and part of the passages can then be examined and cleaned. If still unsatisfactory, the glass must be cleaned out and the grommets and passages below overhauled.

It will be sufficient to call attention to a possible error which may be made when trying the upper cock of a gage fitted to a stand pipe, as in the "New Orleans." Suppose the passage in the upper horizontal leg of the stand pipe should become choked. The gage glass would still be in communication with the boiler through the vertical connecting part and the lower horizontal leg of the stand pipe. If now the upper shut-off cock is tried, as explained above, water would be forced up through the vertical part and down through the glass, thus seeming to indicate too much water in the boiler. As there are no valves between the boiler and stand pipe, the latter cannot be tried separately. To reduce the chances of their choking, the stand pipe passages are made large, and the probability of the above error being made is, therefore, very small.

Safety Valves.—These are fitted to prevent the pressure in the boiler from rising above the safe working limit and to provide a ready and automatic means of escape for the surplus steam. This is accomplished by opposing the resistance of a spring, acting on one side of a valve, to the steam pressure in the boiler acting on the other side, the chamber into which this valve opens being connected to the atmosphere by the escape pipe.

Figures 22, 23 and 24 show examples of duplex pop safety valves of the Navy pattern, the first two showing an outside and a sectional view of the valve made by the Star Brass Manufacturing Company, and the third one, a sectional view of the valve made by the American Steam Gage and Valve Company. The general appearance of the outside of the American valve and its

lifting levers and shaft is similar to that of the Star valve, so that only one outside view is shown.

These valves, as well as those made by other manufacturers, conform to the requirements of the Bureau of Steam Engineering. The type shown here is called the "Duplex," because two valves are enclosed in one casing. They are also made in

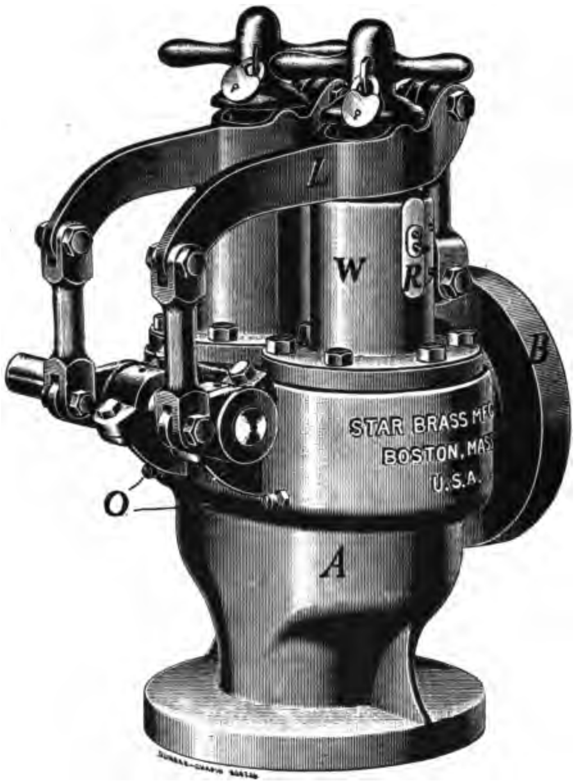


FIG. 22.

the single, triple and quadruple types, but the valves are the same for all types of the same make. The usual requirement is that two or more safety valves shall be fitted, instead of having the necessary area put into one valve. The valves are, whenever possible, placed vertically. When placed horizontally, owing to the play between the wings of the valve and the seat, they are very hard to keep tight.

A is the valve casing, its lower part C having usually a separate and direct connection to the boiler, and its upper part being connected to the escape pipe by the flange B. When C is connected to the main stop valve casing, it must be between the boiler and the stop valve. In both cases, steam is taken from the dry pipe.

Bolted to the top of A are the two cases W, W, for the springs,

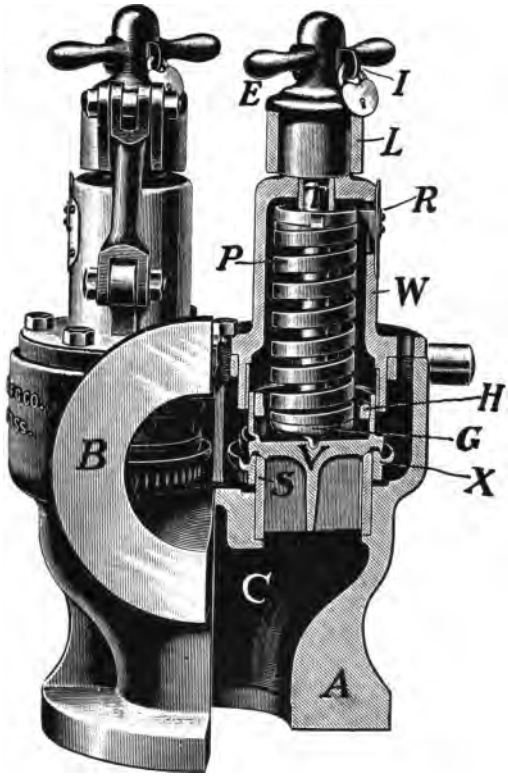


FIG. 23.

each being so fitted that the valve V can be taken out without interfering with the adjustment of the spring P, as will be seen more clearly from Fig. 24.

To move the valve by hand, the lever L, working against the cap E, which is secured to the valve stem T, is provided. By means of the link and arm shown, L is connected to a rock shaft. This shaft is turned by suitable lifting gear, either from the fire

room or from the deck above, the rock shaft arms being so arranged that the valves in each casing are lifted in succession and not together. By means of the handle secured to the valve stem T, the valve V, can be turned on its seat S, without interfering with any other part. Any scale or dirt which may have lodged between the valve and seat can thus be removed. To prevent an accumulation of water from the condensation of escaping steam, a drain pipe leading into the bilge, is attached to the casing A, below the level of the adjusting ring X.

The Spring.—The spring P is of the highest quality of steel, nickel-plated, and square in section. It is enclosed in the case W, to prevent contact between it and the steam and so reduce the chances of corrosion. Each spring is made long enough to allow the valve to lift *one-eighth* of its diameter when the valve has been set at the original working pressure. To overcome the effect of any tilting of the spring when the valve opens, and consequent binding of the wings of the valve against the sides of the seat S, the ends of the spring must be free to oscillate. This is accomplished in the American valve by inserting the independent flanges F, F, which have spherical bearings where they rest against the valve stem T.

In the Star valve, the lower flange G, called the compression plate, is pivoted on the valve, and has two projections which fit into slots cut out of the screw ring H. These slots permit the ends of the projections to move up and down when the spring tilts, without communicating this motion to the valve, the wings of which, therefore, remain truly in line with the sides of S. When the valve is to be examined, the slots in H allow the case W, valve stem T, spring P and compression plate H, to be lifted out together, the valve V remaining on its seat. In the American valve, the valve V is lifted with the spring, to be disconnected after removal by taking out the small set screws and unscrewing the small nut shown on top of the valve.

The casings A and W and valves V are made of standard composition for strength and to prevent corrosion. The valve stem T is made of rolled bronze. The springs are adjustable for pressures up to the test pressure of the boiler.

The Valve.—The valve seat S is a solid nickel casting screwed into the casing A, and extends down to the bottom of the wings on the valve V. It is turned to a cylinder on the inside and

serves as a guide for the wings of the valve, these being slightly smaller in diameter to prevent binding. On the top of S, a narrow conical seat is turned to an angle of 45° for the face of the valve V. Around the outside of the top of S, there is a screw ring X. Valve V, with its wings in the cylindrical part of S,

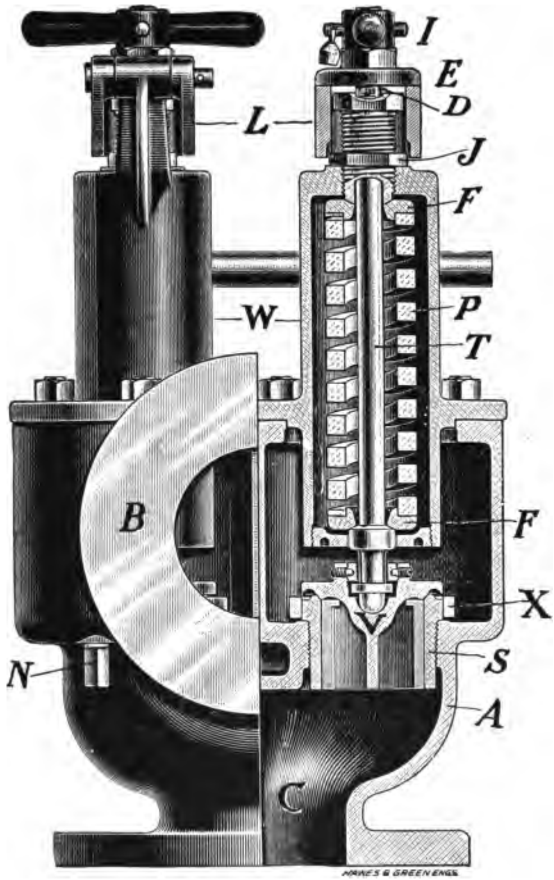


Fig. 24.

rests on the conical seat, and is held in place by the valve stem T, which fits loosely in the valve, as shown, the bottom of the stem being below the level of the valve seat. As will be noticed, the valve extends beyond the face in a sort of projecting lip, the size and shape of which, as well as those of the upper face of the adjustable ring X, vary in the different designs of valves. The object and necessity of the lip and ring will now be explained.

Suppose V to be an ordinary valve with a conical face just covering the seat. The spring P, being under compression to resist a certain pressure, would allow the valve to rise only slightly for an instant when that pressure is reached, as the resistance of the spring to still further compression increases with the amount of that compression. The valve would, therefore, open and close continuously, discharging only a little steam each time. But, if the face of the valve is enlarged beyond the seat, it will be readily understood that, so soon as the valve opens to the pressure, the escaping steam acts on an increased area; therefore, the opening for the escape of steam is increased suddenly, and the valve "pops" and is held open until the pressure has fallen below the opening pressure. To prevent too great a drop in the pressure before the valve closes, or, in other words, to reduce the difference between the *opening* and *closing* pressures so that it shall not exceed five pounds, the adjustable ring X is provided in connection with the deflecting lips. By means of this ring, the opening for the escape of the steam, after the latter has been deflected by the lip, can be slightly changed, and the closing pressure regulated.

X in the Star valve is a screw ring with teeth on its outer circumference. By taking out the screw stop O and inserting a pointed rod between the teeth, the ring can be screwed up or down. In the American valve, the ring is not threaded, but is moved up and down by two screws, one of which is shown at N (the other one being diametrically opposite), which engage with the ring by means of collars. This arrangement is similar to the ordinary stuffing box gland.

Lift of Valves.—It was stated above that the spring must be long enough to allow the valve to lift one-eighth of its diameter when set at the working pressure. This must not be mistaken for the actual distance that the valve lifts when blowing, as this rarely exceeds $\frac{1}{8}$ inch. The area of the valve is calculated for a lift of only $\frac{1}{10}$ inch when blowing at the full steaming power of the boiler. If the spring were short, so that it would allow only $\frac{1}{8}$ or $\frac{1}{10}$ inch movement and no more, it would soon become permanently set. But, by making the spring longer, so that the valve, say a 3-inch one, can lift $\frac{1}{8}$ of 3 inches, or $\frac{3}{8}$ inch, the required $\frac{1}{10}$ or $\frac{1}{8}$ inch movement of the valve will be always within the elasticity of the spring.

The guide for the upper end of the valve when it lifts is somewhat different in the two types shown. In the Star, the valve casting is extended in a cylindrical shape, which permits it to slide in the cylindrical bottom end of W. A liner is shown in W in the cut, which is not put in naval valves, as everything is of composition. In the American, an enlargement on the valve stem fits a cylindrical hole in the bottom of W.

Resetting Valves.—When a change is to be made in the opening or blow-off pressure of the valves on a boiler, the fires are put in such condition that the steam pressure can be easily raised to the blowing-off point for a few minutes at a time. The caps E are taken off by unlocking and removing the pins or keys I, I. These pins not only prevent tampering with the adjusting heads D, but secure the handle H to the valve stem. The details of the adjusting gear are not shown in the Star valve, and reference is, therefore, made to Fig. 24, but the description will answer for both.

The lock nut J, on top of case W, is slacked off and the adjusting head D set to the new pressure desired, by screwing down on it to increase, and screwing up to decrease the blowing-off pressure. The index R on the Star valve and the graduations on the stem of the American valve show the positions of D.

The lock nut is now set up and the steam pressure allowed to rise for a short time so that the valves will blow or pop. Observe the opening and closing pressures by the steam gages on the boiler. If the valve does not pop promptly, the adjusting rings X, X, must be turned up so as to move them nearer the valves; if the closing pressure is reduced too much, turn rings down so as to move them further away from the valves. Care must be used in turning the adjusting rings, so that both will be moved exactly the same distance, otherwise the equal adjustment of the two valves will be destroyed.

When both opening and closing pressures have been satisfactorily adjusted, secure the screw stops O, O, in the Star valves, and then replace caps E and the handles and lock them in place.

While it is preferable to set the valves by steam, it can also be done, in some cases, by filling the boiler with water, disconnecting the main escape pipe, and watching for the valve to lift as the pressure is put on from the main feed pump.

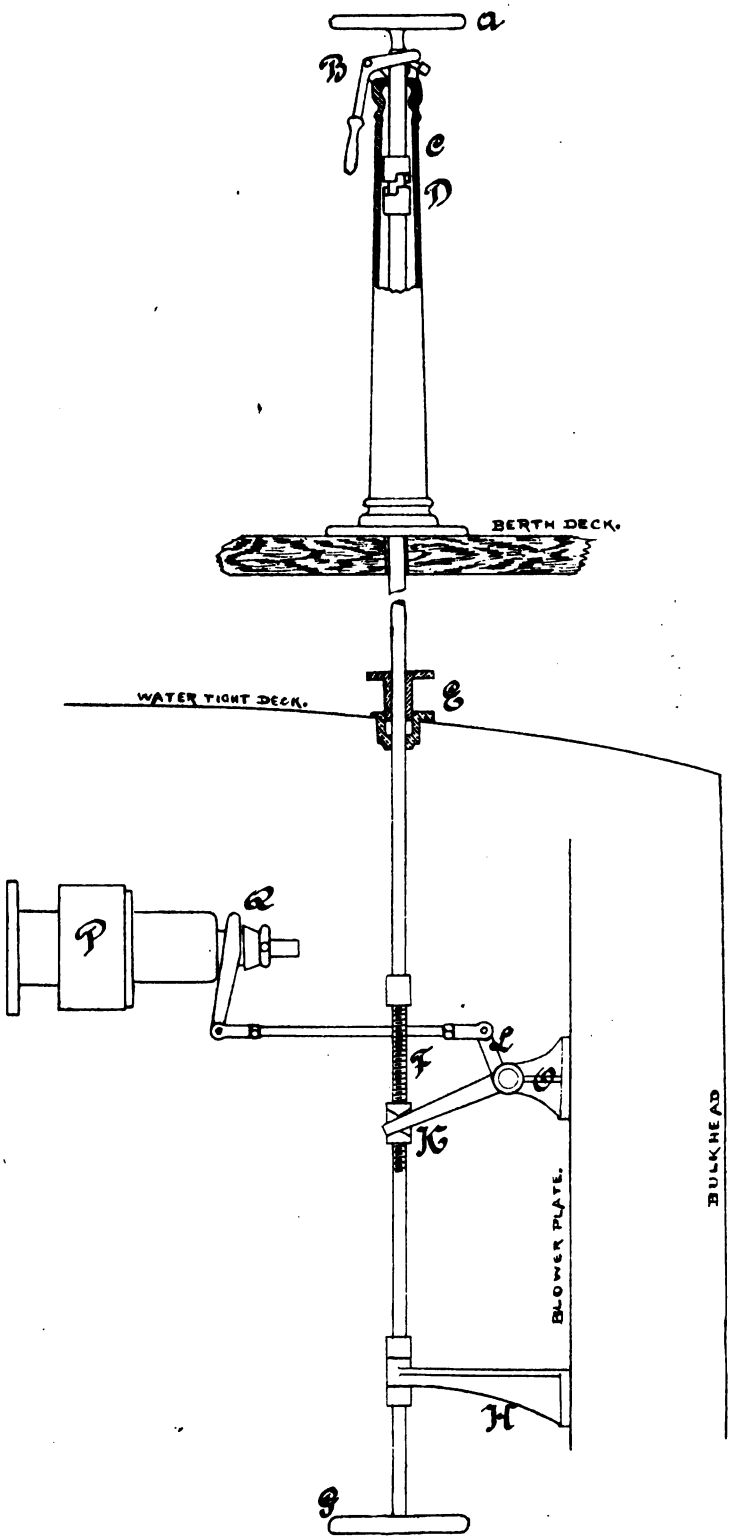

a
B
C
D
BERTH DECK.
WATER TIGHT DECK.
E
Q
P
L
F
O
K
BLOWER PLATE.
BULKHEAD
H
G

FIG. 25.

Lifting Gear.—Besides the automatic lifting of the valves by steam pressure, mechanism is always fitted so that the valves can be raised by hand from the fire room, a passage way outside of the fire room, or the deck above. The last two connections are emergency ones, for use in case of accident when it is impossible to work the valves from the fire room.

Fig. 25 shows one of the older arrangements of this mechanism and will give the necessary idea how to apply the principle to the simpler requirements for the vertical safety valves shown above. P is the safety valve placed horizontally in this case, and having a direct lever Q, instead of the compound levers and rock shaft shown in the valves above. G is the hand wheel for turning shaft F from the fire room, and A, for turning F from the berth deck. Part of the shaft F is threaded and over this part the nut K, which engages with a bell crank L, works up or down. Ordinarily, the hand wheel A is left disconnected, by raising it and thus releasing the clutch coupling at C D. When the wheel is dropped and the clutch engaged, the safety valves may be lifted from the deck. E is a stuffing box at the protective deck. To prevent rusting, the various joints or bearings of the lifting gear are bushed with composition.

Care and Overhauling of Valves and Lifting Gear.—In order to ensure the proper working of valves and the gear, the Regulations require that "The safety valves shall be partially lifted by the hand gear at least once each week when not under steam." Should the gear work hard, the joints should at once be overhauled, cleaned and oiled. As a further precaution, these joints should be disconnected and thoroughly overhauled at least once in six months. The threads of the raising screw, being more liable to accumulation of coal dust, on account of the oil or tallow used to lubricate them, require particular attention.

Sentinel Valve.—In addition to the main safety valves on each boiler, a small safety valve, usually about ½ square inch in area, is fitted, and is set to blow at a few pounds less than the opening pressure of the main valves. It discharges the steam into the fire room, and the noise thus made gives warning that the steam pressure must be reduced at once to prevent the main safety valves from blowing.

The older form of sentinel valve, still in use on some of our ships, was an ordinary lever valve, but the newer ones are all

spring safety valves. They are not pop valves, but plain disc valves. No lifting gear, other than a short hand lever, is fitted.

Steam Gages.—Each boiler has attached to it one or more gages by means of which the steam pressure is indicated. Fig. 26 shows one of the types usual in our Navy, with the screwed bezel or front, the glass cover, and the dial removed. For boilers working at 160 to 180 pounds pressure per square inch, the dial is usually graduated to 240 pounds. For higher pressures, the springs are stronger and the dial is graduated to 350 pounds.

The double Bourdon spring S, consists of seamless-drawn tubing, elliptical in section, and either plain or corrugated as in the Star gage shown. The upper ends D, D, are closed, and the lower ends open into the hollow socket C which, at E, is connected by a pipe with the steam space of the boiler. The bracket B is fixed to the plate K, which rises from C and supports the bushing for the axis of the pointer and the pin for the slot in the sector H. By the system of levers, one end of which is connected to the ends D, D, of the spring S, and the other, to the toothed sector H, any motion of D is multiplied and transmitted to a small pinion on the axis of the pointer and engaging with H.

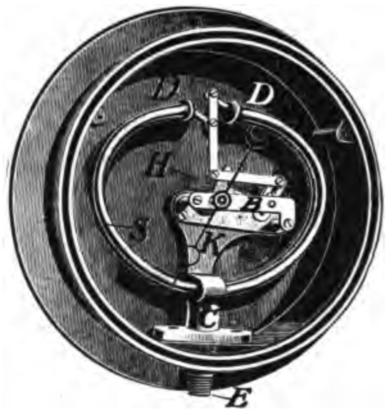


FIG. 26.

The spring S, being elliptical in shape, with the longest diameter perpendicular to the curvature of the spring, any increase of pressure on the inside will tend to equalize the diameters of the ellipse, and thus cause the tubes to straighten, that is, move the closed ends away from each other. The elasticity of the metal of the springs, if not exceeded, will bring the ends back to their normal position when the pressure is decreased. A hair spring takes up the back-lash in the movement, when the pressure is going down, and a small pin on the dial stops the pointer at a little above zero. The springs are of such shape and strength that no permanent set is acquired under any pressure shown on the dial. All interior parts are made of non-corrosive materials,

and the movement is made as light as possible. The casing is made of brass, nickel-plated.

To prevent the ill effect of actual contact of the steam with the springs, all gages intended for steam must have a siphon fitted to them below E. The siphon is made by bending a complete circular loop in the pipe leading to the boiler. In order that it

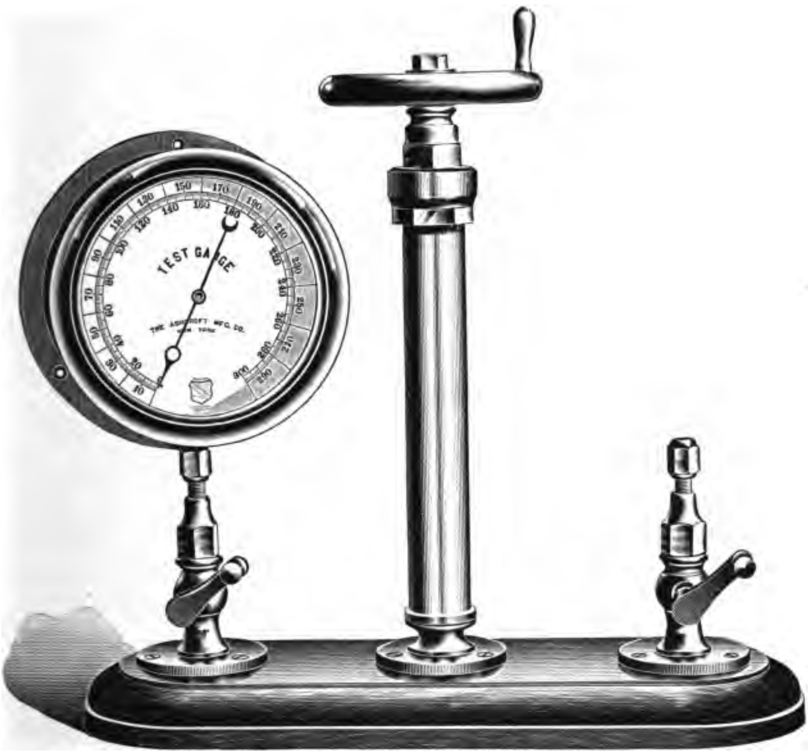


FIG. 27.

may be effective, the siphon is made sufficiently large to contain enough water to fill both springs when under pressure, and so fitted that this water seal will not be drawn out of the siphon when the pressure is off. A small cock, by which the gage can be shut off, is fitted between the siphon and gage.

The dial is graduated for every five pounds by comparison with a mercurial column. To make sure that the gages on board give reliable indications, they are tested periodically.

Gage Testing Apparatus.—There are two kinds of testing outfits supplied, one of which, made by the Ashcroft Manufacturing Co., is shown in Fig. 27. The cylinder in the middle is a screw pump, the plunger of which is worked by the hand wheel, and is connected by a pipe to the two cocks at the ends of the base. A standard test gage, the dial of which is graduated to single pounds, is screwed on one of these cocks, and the gage to be tested, on the other. The hand wheel being run out, the pump cylinder and connecting pipes are filled with water through one of the cocks, and then the gage screwed into place. Pressure is now applied by screwing in the hand wheel, the readings of the gage for every five pounds being compared with the test gage from zero (or, from the stop pin, which in high pressure gages is set a few pounds above zero), to the working pressure and back again. If the difference between the two gages is constant, the pointer can be removed by the lifter provided and set in the correct position. A gradually increasing or decreasing difference may be corrected by a slight change in the position of the slotted lever. In a modification of this apparatus, the screw pump is replaced by a lever pump.

In the second kind of testing outfit, the pressure is produced by weights and communicated directly to the gage to be tested. No test gage and pump are needed. There is a pipe, turned up at the ends, secured in a base and fitted at one end with a cock for a gage, similar to Fig. 27. At the other end, there is an open cylinder in which a snug-fitting plunger, exactly one square inch in area, can move up and down easily. The top of this plunger is fitted with a tray on which the weights are piled, thereby increasing the pressure per square inch as desired. Glycerine is generally used in this apparatus, instead of water, as it lubricates the cylinder. While testing a gage, the plunger and its weights should be rotated at intervals to insure its working with the least friction.

Stop Valves.—In the earlier designs, each boiler is fitted with one main and one auxiliary stop valve, connected, through openings in the shell of the boiler or steam drum, with the dry pipe. In later designs, these two valves are in the same casing, thus requiring only one opening to be cut in the shell. In the recent large ships with tubulous boilers, where the main steam pipe takes steam from the boilers only indirectly, by way of the auxil-

iary pipes, there is only one stop valve on the boiler, which is called the main stop valve; another stop valve which controls the supply from a group of boilers, is fitted in the branch leading to the auxiliary steam pipe.

All of these are *self-closing valves*, that is, they will close automatically whenever the pressure under the valve falls below that on top of it. Suppose a battery of boilers under steam and that one of them is injured, either by accident or from a shot in action; water or steam would rush out of the ruptured or punctured place, the pressure would fall, and the main stop valve, being placed to close towards the boiler, would be forced down against its seat and separate the injured boiler from the rest of the battery.

With valves fitted in the branch pipes, as just described, they are designed to close *towards the engines;* a rupture in the steam pipes, between these valves and the engines, would cause them to close and shut off the supply of steam from the boilers. This arrangement of valves provides a double safeguard, and the disastrous effects of a rupture in either the boiler or steam pipes are reduced as much as possible.

Ordinary Stop Valve.—With the ordinary stop valve shown in Fig. 28, which can be closed by hand only, it takes considerable time to close it. These valves are, therefore, not used as boiler stop valves, and are now fitted in steam piping only where their quick opening or closing is not of importance. All parts of these valves are of composition.

C is the *valve chamber*, which has openings at D and E for the supply and discharge of the steam, the connecting pipes being bolted to the flanges. On top of C is an opening, which is closed by the *cover* or *bonnet* B by means of *stud bolts* and nuts. The chamber is divided into two parts by the irregularly-shaped diaphragm D, in which is an opening which can be closed by the *valve* V. The valve is shown open in the figure, the *valve face* F having the same bevel as the *valve seat* W. Communication between the two parts of the valve chamber, and, therefore, between the two connecting pipes, may thus be opened or closed at will by opening or closing valve V. Connected to V is the cylindrical *valve stem* A, which has a thread cut on its upper end. This thread works in a corresponding one cut in the *yoke* Y, so that by turning the *hand wheel* T, keyed to the top of A, the valve V is raised or lowered. All naval valves, with very few exceptions,

are made to open *left-handed,* i. e., by turning the hand wheel against the motion of the hands of a clock, and to close *right-handed.*

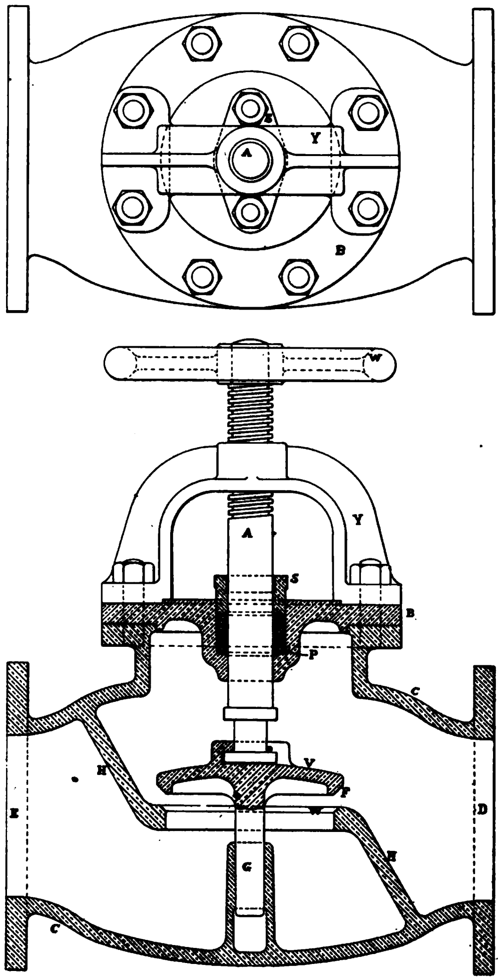


FIG. 28.

The cover B is cast with a boss in the center which is bored out at the bottom to allow A to pass through freely. Above this hole, the boss is bored out to a larger diameter for the *stuffing box,* which contains the *packing* P and the *gland* S, the latter being *set up* by means of the two nuts shown in the plan. By this

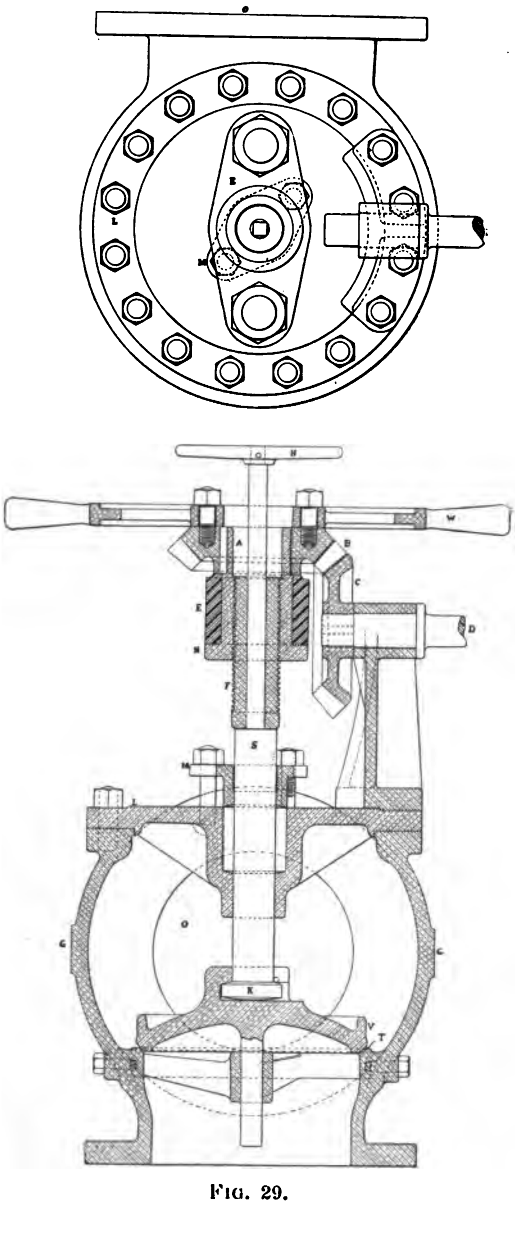


FIG. 29.

means, A can pass through the cover without the escape of steam. Valve V is connected loosely to its stem by a collar K on the lower end of A, which fits into a horse-shoe recess in the top of V. A small pin across the opening of the recess prevents side motion of the valve. A projection G on the lower side of V fits loosely in a guide cast in the chamber.

Self-closing Stop Valve.—The ordinary form of this valve, with part of the gear for working it from the deck, is shown in Fig. 29. G is the valve chamber, with inlet at I and outlet at O, in this case at right angles to I.

The lower view is a vertical section through the center, and the top one, a plan of the outside with parts omitted for clearness.

The valve V is secured to the valve stem S as before. A short distance above the top of the stuffing box, S is reduced in diameter and ends at the cross bar handle H, which is pinned to it. The hand wheel W does not, as in the ordinary stop valve, raise and lower the valve, but only regulates the amount of opening which may be given to the valve.

Surrounding the reduced part of S is a threaded sleeve F, which may slide on S. The thread on F works in that of a bushing N, which may turn in the steel yoke E, but is prevented from rising by the flange or collar which bears against the under side of E. The bushing extends to the under side of wheel W. Between W and the top of E is the bevel wheel B, which is screwed on and keyed to the bushing, and to which is bolted the hand wheel. Geared to B is the bevel wheel C, which can be turned by the small shaft D leading to the deck. D turns in and is supported by a bracket bolted to L. Yoke E is held in place by two studs screwed into the bonnet L of the valve. On these studs slides a forked guide, not shown, which is secured to the lower end of F. This guide keeps F from turning, but allows it to have sliding motion on S.

When W is turned, either by hand or by means of the bevel gear, bushing N turns, and sleeve F will, therefore, turn and move along S, rising into the opening A at the top of N. When F has been moved the required distance, stem S and the valve are pulled out, or the valve *opened*, until the enlarged part of S is stopped by F. When the valve is being opened, handle H should always be pulled out as W is turned, in order to prevent the violent opening of the valve when the excess pressure under it is great enough to overcome the friction in the stuffing box.

These valves are fitted to boilers and pipes in a horizontal position, when possible, so that the weight of V and S will not enter as a factor in their movement when differences of pressure occur on the two sides of V. If fitted in a vertical position, the movement of V may be a violent one, and large valves have been broken from this cause. They are, however, easier to keep tight when fitted vertically.

When these valves are used as engine stop valves, a small *by-pass* pipe and valve are fitted to connect the two sides of the valve V, and thus to partially equalize the pressure and consequently make the opening of the valve by hand easier.

Another type of automatic stop valve, used on the "Hopkins," "Hull" and other vessels, is described under "Steam Pipes."

Dry Pipes.—In each boiler or steam drum, a thin brass or tinned copper pipe is fitted as near the top as possible. This pipe extends nearly the length of the boiler or drum, and is perforated on its upper side with slits or holes, of such number and size that the sum of their areas is equal to that of the steam pipe leading from the boiler. Usually one end of this pipe is secured to the stop valve nozzle and the other end is closed. Steam from the boiler can, therefore, get into the stop valve chamber only by rising nearly to the highest point in the steam space, and thence through the slits in the top of the dry pipe. As this pipe extends nearly the whole length of the boiler, the steam is collected from all parts of the steam space instead of rushing up from one place into the large stop valve nozzle. The evaporation is, therefore, more uniform and any tendency to priming is much reduced. For this same reason, safety valve chambers are now connected to the dry pipe, either directly or through the stop valve chamber, instead of opening direct into the steam space.

Fig. 30 shows a T-casting fitted on each of the "Alabama's" boilers, which reduces the number of holes to be cut in the boiler shell for the various stop and safety valves to one, all valves taking steam from the dry pipe.

G is the boiler shell to which is riveted the nozzle F, which forms a seating for the casting E. To the internal spigot of F is fitted a vertical branch H of the dry pipe, the latter being horizontal and closed at both ends. A is the flange to which the dynamo stop valve is bolted and D that for the auxiliary stop valve, both self-closing, with their spindles horizontal. B is

the seating for the main stop valve and C that for the safety valves. The spindle for the main stop valve is, in this case, vertical.

One or more small drain holes are made in the under side of the dry pipe to prevent accumulation of water.

The dry pipes and drains of the steam drums must be examined frequently to ascertain if the holes in them are clear (Regulations, Art. 1609, par. 6).

Bottom and Surface Blow Valves.—These valves are fitted for the purpose of blowing oil, sediment, or dirty water from the

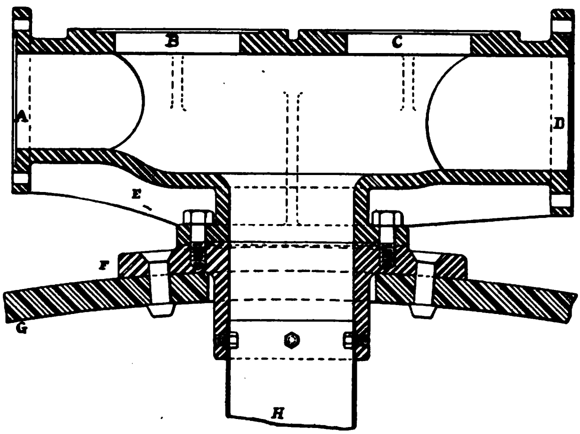


FIG. 30.

boiler overboard. Both have internal brass pipes in shell boilers; in tubulous boilers, with small or short mud boxes, the internal pipe of the bottom blow may be omitted. The internal pipe of the bottom blow is lead to the bottom of the boiler; that for the surface blow is lead to near the water line at the center of the boiler or drum and ends in a scum pan. The valves are of composition throughout, are secured to the boiler near the front, and are opened against the boiler pressure.

In each boiler compartment there is a bottom blow pipe, made of seamless-drawn copper, which connects all the bottom and surface blow valves to a sea valve in the same compartment. This pipe is usually under the floor plates and, like other copper pipes in the bilge, must be kept well painted on the outside and not

allowed to come in contact with the inner skin of the ship. A stop valve is put in the blow pipe close to the outboard discharge, to cut off this pipe from the sea valve, as the latter is kept open when under steam.

Fig. 31 shows the method of fitting the internal blow pipe C to the valve A. The latter has a nipple or spigot which projects through the shell of the boiler or drum B, and makes a tight fit with the pipe which has been expanded into the shell. The valve is secured by bolts, not shown, passing through the shell and the valve flange.

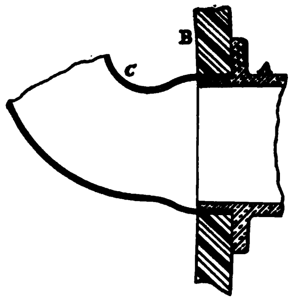


FIG. 31.

Bottom Blow Valves.—Formerly, when salt water was used for make-up feed, the *bottom blow valve* was also used to blow out the denser brine from time to time, and this, by permitting the introduction of new and less concentrated sea water through the feed valve, helped to keep the concentration of the water in the boiler below the required limit. It was also used to *blow down* or blow all of the water out of the boiler, when through steaming and after the fires were hauled. At present, with fresh water as feed, it should not be necessary to use this valve for the purpose of reducing the concentration. Its use to blow down the boiler is, as pointed out before, no longer permitted. Yet it often becomes necessary to get rid of mud or other sediment from dirty fresh water, and for this purpose it may be used while the boiler is under steam. This is especially necessary in tubulous boilers. The Babcock and Wilcox Company recommend that the bottom blow be used at least twice a day when steaming regularly, by opening the valves wide and immediately closing them. A more frequent and freer use is recommended when the boilers are under banked fires or steaming slowly, as, on account of the less active circulation under these conditions, there is greater opportunity for deposits to settle on the heating surfaces.

The bottom blow valve also serves another purpose. Through a pipe connection, leading from the blow pipe in each compartment to the auxiliary feed pump, the water in any boiler may be pumped out by opening the bottom blow valve, after steam has died down.

Surface Blow Valve.—This valve is more important than the bottom blow valve, for, as pointed out before, oil on the heating surfaces is a great source of danger. In order to get rid of any oil that may get into the boiler, the internal pipe from this valve is fitted as shown in Plate II. H is the valve, and SP is the scum pan placed near the ordinary water line and near the center of the boiler or drum, and as the water in it is comparatively without movement, it serves as a collector of the heavy particles of mineral oil. In order to be effective, the surface blow should be used often, but only for a very short time, and the water level should then be slightly above the top of the scum pan.

With shell boilers, unless there is evidence of much oily scum, blowing once each watch for about 10 to 15 seconds will usually be sufficient. The Babcock and Wilcox Company recommend the use of the surface blow on their boilers once each watch, opening the valve wide and immediately closing it. When, on coming into port, it has been decided that a boiler is to be examined and cleaned internally, the surface blow should be freely used immediately before the engines are stopped. After the boiler has been disconnected and the steam pressure has fallen, the surface blow should be used again.

Circulating Apparatus.—In shell boilers, which contain a large volume of water, which is heated very slowly by the natural circulation when the fires are started, some means of inducing artificial circulation must be provided. The unequal heating of the top and bottom parts of a boiler, especially if steam is raised quickly, sets up enormous strains which result in leaks, and, if frequently repeated, in weakness.

Fig. 32 shows one method of inducing a circulation and so a more uniform heating of all parts of the boiler. This apparatus is called a *hydrokineter,* and can be used without interfering with the operation of the feed pump. A few of our ships were fitted with a circulating apparatus which required the use of the feed stop and check valves and necessitated shutting off the boiler from the feed pipes. This form is no longer permissible. The hydrokineter consists of the stop valve B, on the outside and near the bottom of the boiler, which admits steam from the auxiliary steam pipe, and the circulator K, L, S, M, inside of the boiler. Both parts are bolted together to the shell H. As shown in the figure, the stop valve is slightly open, admitting steam at A, which is

forced out of the tapered nozzle at the end of K. This induces a current in the surrounding water, which finds its way to the jet through the openings O, O, the stream of heated water passing out of the last nozzle M with considerable velocity. Local circulation is thus started, which, with the help given by the heated water, is gradually communicated to the whole mass of water in the boiler.

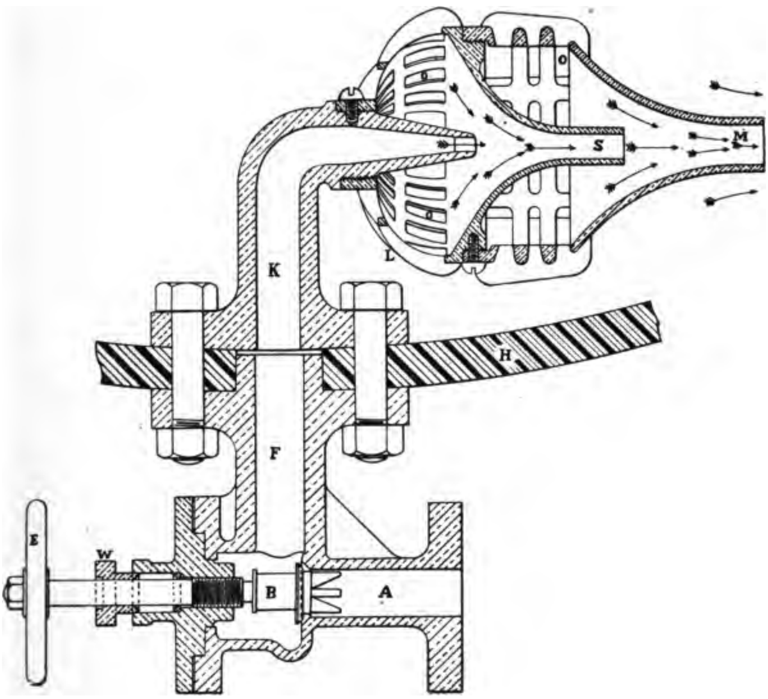


FIG. 32.

The hydrokineters are usually started from ten to twelve hours before the fires are lighted and worked slowly, so that the auxiliary boiler, from which the steam is taken, need not be forced too hard. When this apparatus is to be used, the water level must be left low enough in the beginning to provide for the increase due to the condensation of steam entering the boiler through the hydrokineter.

Where no circulating apparatus is fitted, one of the feed pumps may be used to draw water from the bottom of the boiler, through the pumping-out pipe and its valve, and discharge it

through the feed pipe and check valve back into the boiler. Great care must be used to see that the blow valves on the other boilers are closed, as the pipes from these valves and from the pumping-out valves are, generally, in the same system.

When the pressure in the boiler in which steam is being raised is near that in the auxiliary boiler, the hydrokineter, or the pump, must be stopped, as neither will then work.

Salinometers.—Attached to every shell boiler, in a convenient position, is a *salinometer* for the purpose of ascertaining the degree of salinity, density, or *concentration* of the water in the boiler. The instrument usual in our Navy is shown in Fig. 33, and consists of the *pot*, formed by the two cylinders *c* and *e*, and the connecting channel *d*, the *thermometer l*, and the *hydrometer k*. The pot shown here may be replaced by an ordinary, deep handled pot, into which water from the boiler is drawn; the one described is, however, much more convenient.

Valve *a* is connected to a small pipe leading from the water space of the boiler, near the bottom. A cock is put in this pipe close to the boiler, so that the latter can be shut off if the pipe should be broken. *h* is a drain cock for cylinder *e*. The thermometer is held in place by spring clips. The hydrometer *k* is of glass for ordinary use, there being a standard one of brass on each ship. It is a closed tube, enlarged in the middle to give buoyancy, with a lower bulb weighted with shot to make it float upright. A paper scale on the inside of the stem of the hydrometer gives the degree of concentration for three temperatures, 190°, 200°, and 210°, of which the figure shows the first two. The scale is graduated to show the number of pounds and quarter pounds of salt contained in 32 pounds of the water to be tested. The average sea water is taken as containing $\frac{1}{32}$ part of solid matter (D. K. Clark gives $\frac{1}{30}$), and its density or concentration is represented by 1. The concentration of pure fresh water is, of course, zero and is marked by F. W.

The principle utilized in a hydrometer is that, when a body floats freely, the weight of the body is equal to that of the liquid displaced. The weight of the hydrometer being constant, it follows that it will sink further in fresh water than in the denser sea water. By noting the line of flotation on the stem for various degrees of concentration at a given temperature, the scale for that temperature is obtained. For other temperatures, the scale varies

about $\frac{1}{8}$ of $\frac{1}{32}$ for every ten degrees Fahrenheit, that is, the hydrometer will float higher in the cooler and, therefore, denser water. Hence, if the hydrometer has only one scale, which has been graduated at 200° F., and the temperature of the water in the pot is 190° when the reading of the hydrometer shows 2, the actual concentration would be $2\frac{1}{8}$, while for a temperature of 210°, it would be $1\frac{7}{8}$. The salinometer readings are entered in the log in units and eighths, the denominator being omitted, it being understood that a concentration of $1\frac{1}{2}$ means that many thirty-seconds.

When the concentration, or saturation as it is often called, is to be taken, the hydrometer is removed and valve *a* opened. The water from the boiler is forced into tube *b*, the end of which is closed by the cap *o*, and finds its way through the small holes near the top, into the open cylinder *c*, and through *d* into *e*. Cylinder *e* is kept full to a convenient height by means of the overflow pipe *f*, which takes the surplus water to the bilge. When the temperature of the water is falling, the hydrometer is put in, and the concentration then read off on the scale corresponding to the temperature.

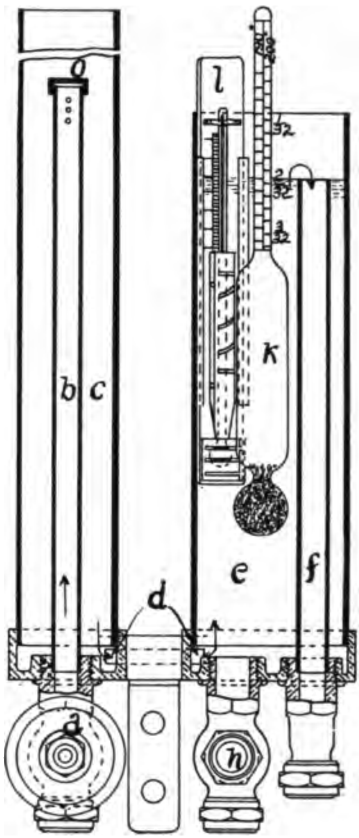


FIG. 33.

The above instrument does not measure the concentration very closely; while it is sufficiently accurate for shell boilers and evaporators, more delicate tests, which can be made by chemical means only, are required for tubulous boilers.

The ordinary nitrate of silver test for the purity of drinking water made by the distillers has been in use for a long time. Nitrate of silver has a strong affinity for chlorine, and as sea water contains sodium chloride or common salt (about 2.35%),

and magnesium chloride (about .31%), it will attack these and form a milky-white precipitate. The slightest trace of chloride, although this may not be sufficient to be harmful, will thus be discovered in the water. But, this test, as usually made on board ship, is not a quantitative one, and has often been the cause of much useless refinement and consequent extra demand on the already over-taxed evaporating plant. To show the exact number of grains of chlorine in each gallon of water, some other chemical, which the nitrate of silver will not attack until all of the chlorides have been converted into silver chlorides, must be used.

One of these methods, described below, is now utilized by the Babcock and Wilcox Company, and the testing outfit is supplied by them for their boilers. This method is adapted from the volumetric determination of the chlorine, by the use of potassium chromate, as devised by Fr. Mohr, a German chemist.

Chlorine Testing Outfit and Test.—This consists of a graduated bottle, a bottle of silver solution containing 4.738 grains of silver nitrate to 1000 pounds of pure distilled water, and a bottle of chromate indicator, which is a 10 per cent solution of pure neutral potassium chromate.

To make the test, fill the graduated bottle with the water to be tested to the zero mark. Add one drop of chromate indicator, then add slowly the silver solution, meanwhile shaking the bottle. When nearing the full amount of silver solution required, the water will turn reddish for a moment, and then back to yellow again when shaken. The instant it turns yellowish-red and *remains so*, stop adding the silver solution. The reading on the graduated bottle at the level of the liquid will give the number of grains of chlorine in one gallon. For instance, if the level is midway between 100 and 150, there are 125 grains of chlorine per gallon. The chlorine should be kept *below 50* at all times, and the nearer zero the better; if above 50, the cause must be found immediately and removed so soon as possible.

When the chromate is dropped in, the water is tinted yellow. The addition of the silver nitrate changes this, if the water is high in salt, to a milky-yellow, and later, when all the chlorides have been converted, to yellowish-red and red, due to the formation of chromate of silver. It is not necessary to keep adding the silver solution until the color becomes deep red, as the delicacy would be destroyed. The change from yellow to yellowish-red must, however, be distinct and be permament on shaking.

Slight alkalinity of the water to be tested does not interfere with the reaction, but the water must not be acid. Strong alkalinity may be neutralized by nitric acid, and acidity, by sodium carbonate.

A gallon, 231 cubic inches, of sea water, weighs 59,889 grains at 62° F. In this there are about 1871 grains of solid matter, on the basis of 1 in 32, or 3.125%, of which 1593 grains are chlorides. At 200° F. these weights become about 57,703, 1803, and 1539 grains per gallon, respectively. As the last quantity represents a concentration of 1 on the 200° scale of the hydrometer, the greater delicacy of the chemical test is apparent.

Air Cock.—Each boiler is fitted with a small cock at the highest part of the shell or steam drum, to permit the escape of air when filling the boiler above the level of the gage cocks, and to show, by the escape of water, that the boiler is quite full. A copper drain pipe leads down to the bilge with its end in plain view, thus giving warning when the boiler is full and keeping the surplus water away from the boiler clothing. In some tubulous boilers, as will be seen later, parts of the tubes are higher than this cock and cannot, therefore, be kept entirely full of water.

Drain Cocks.—One or more drain cocks are fitted to each boiler in such positions that the boiler can be thoroughly drained into the bilge.

Valve for Filling Boilers.—The more recent boilers are fitted with a valve having an outside thread, to which a hose can be coupled when filling the boiler by means of the pumps of a water boat or the pressure on shore.

Man and Handhole Plates.—These holes are cut in the boiler shell and heads, or in the steam and mud drums for the purpose of examining and cleaning the interior surfaces. In large shell boilers, all openings of this kind can be made large enough to admit a man, but in some parts of tubulous boilers, handholes only can be cut.

Manholes, which are not made by flanging the sheet through which the hole is cut, are re-enforced by a *stiffening ring* riveted to the sheet. The manholes are closed by *plates*, flat or dished in form, which are held in place against a gasket by *dogs*, *studs* and *nuts*. These plates are on the *inside* of the sheet, and have riveted handles for easy manipulation. As the joints of boiler man and handholes are very important ones and require great

care in making, each plate and its dogs and nuts are marked for the hole to which they have been fitted, and the correct position of the plate in the hole is marked on the plate and the boiler.

Fig. 34 shows a flat, built-up manhole plate for one of the holes at the side of a wing furnace in a shell boiler, where the ordinary elliptical hole could not be cut. S is the lower head of the boiler, flanged inwards for the hole M. The plate is made of two thick-

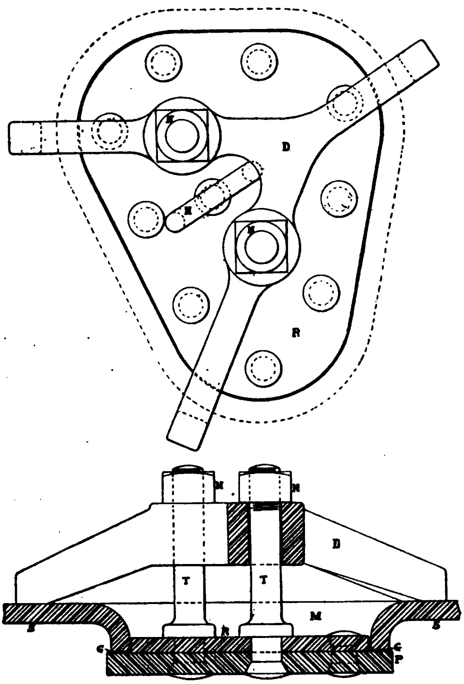


FIG. 34.

nesses, P and R, riveted together. Studs T, T, are riveted to the plate at the bottom and are threaded at the top for the nuts N, N. The dog D, in this case having three legs, bears against the outside of the boiler shell and thus gives a bearing surface for the nuts. The manhole M is slightly larger than the outer thickness R of the plate. H is a handle riveted to the plate.

Manhole Gaskets and Joints.—The joint between the surfaces of the plate and the manhole is made steam-tight by means of a *gasket* G, Fig. 34. The metal surfaces are first fitted to each

other as accurately as possible. A gasket of some yielding substance, like rubber, Tuck's, or other packing, or asbestos card board, is then laid around the lip of the manhole plate and rests on the fitted surface of the plate. In order that the gasket may stick to the plate and not to the boiler, the plate surface is coated with red or white lead and the boiler side of the gasket with black lead and chalk. Boiler gaskets of the right shape to fit the various manholes are usually kept in stock, the metal templates from which they are made being carefully marked and preserved. If the gasket cannot be cut out whole, the ends of the material should be beveled and made to overlap each other, the lap being either stitched or bound with twine. With carefully fitted metal surfaces, the gasket need not be over $\frac{1}{8}$ inch thick, but if the plate fits badly, a slightly thicker gasket will be required, and, sometimes, a ring of lamp wicking at the base of the lip on the plate. Before using new gaskets, they should be thoroughly soaked in black lead and boiled linseed oil.

The gasket is accurately put on the manhole plate while the latter is on the fire room floor. The prepared plate is then carefully shoved through the manhole and put into its correct position by the marks. It is then drawn into place and held there by the handles, a last look having been taken to see that the gasket is still correctly fitted. Another man then puts on the dogs and nuts, and the latter are set up until the plate is secured. The nuts should not be set up too hard. While steam is being raised, the nuts should be set up more, a little at a time, until there is a good pressure in the boiler. If these directions are carefully followed, dangerous accidents, annoying delays, and loss of much fresh water will be avoided.

Uptakes.—The general arrangement for a double-ended shell boiler is shown in Plates I and II, and for tubulous boilers in Plates V and VI.

The lower part of the uptake of shell boilers consists chiefly of the uptake doors which are opposite the nests of tubes. The space between these doors and the boiler and extending over the area covered by the tubes, C in Plate II, is generally called the *front connection* in return tube boilers, and the *back connection* in direct tube boilers, and the doors V are often called connection doors. It will be noticed that, at a little distance above the tubes and high enough to bring it above the water level in the

boiler, the uptake is carried clear of the boiler heads, so that the hot gases cannot strike the nuts of the braces.

The uptakes are made of two or three thicknesses of thin wrought iron or steel plates. Three thicknesses are now used on all boilers. These plates are built on angle, channel or Z bars, which give the necessary stiffness to the whole structure, and separate the thicknesses from each other so as to leave a space of from 2 to 3 inches between them. The lower part of the uptake is bolted to the heads and shell of shell boilers, and to the top of the casing of tubulous boilers.

The upper part of the inner sheet or thickness of the uptake is bolted to the lower part of the smoke pipe, the holes in this sheet being oval to allow for expansion. The space between the inner and middle sheets is an air space, the top of the middle sheet being bolted to the bottom of the outer casing of the smoke pipe similarly to the inside sheet. With shell boilers, the bottom of this air space is closed just above the uptake doors, and small sliding doors, three of which are shown in Plate I, are fitted, through which the hot air from the fire room may escape when steaming under natural draft. With tubulous boilers, the air space is open at the bottom. The space between the middle and outer sheets extends from the top of the ventilating dampers, if fitted, to within 12 or 18 inches of the protective deck, and is filled with magnesia. If only two thicknesses are used, the air space is omitted, the magnesia remaining.

With tubulous boilers, a swinging damper is generally fitted in the uptake of each boiler to regulate the draft, and doors are fitted at convenient places to give access to the interiors of the uptakes. These dampers are so arranged that they can be easily operated from the fire room, and are sometimes fitted in the uptakes of shell boilers.

Uptake Doors.—These are made similarly to the uptakes, sometimes a baffle plate, set off from the inner plate about 2 inches, being added for protection against the heat. These doors are hinged, have latch handles to keep them closed, and are made large enough and so hung that, when open, they will leave the whole nest of tubes easily accessible. As will be seen from Plate II, the connections are at an angle to the boiler front, so that the space increases as the volume of gases increases by the discharge of the successive rows of tubes. Hooks are riveted to the outside

of each door on which the ash pit doors are hung when not used to close the ash pit.

Smoke Pipes.—The number of smoke pipes varies from one to four, depending on the arrangement of boilers, and they are usually arranged along the fore-and-aft center line of the ship, but in some cases, are in pairs athwartship.

Plate XV is a plan of the installation of eight Babcock and Wilcox boilers, or one-third of the whole number, on the battleships "Nebraska," "New Jersey" and "Rhode Island." Plate XVI is an elevation, part in section, of the same.

There is one smoke pipe for each group of eight boilers, the uptakes of two boilers combining in a square leg of the smoke pipe. These four legs combine in the round part of the pipe at a short distance above the top of the center line bulkhead. This arrangement of uptakes and smoke pipe will answer generally for all ships having tubulous boilers.

The pipe is made with an outer casing, with an air space between, which permits the hot air from the uptake air space to reach the atmosphere, besides reducing the radiation from the pipe and the consequent loss in draft. The outer casing is perforated near the protective deck. Hot air from the fire room space below the protective deck is drawn up, and thus helps to ventilate that space and give a better circulation of air in the air space of the smoke pipe. The weight of the whole pipe is taken on the protective deck, through the outer casing. The inner pipe has an angle-iron ledge which supports the armor bars. The part of the smoke pipe which passes through the protective deck is generally square for some distance; above this, it is circular to the top.

Where there is a deck between the main and protective decks, as the gun deck of the "Alabama," "Virginia," and other classes of battleships, an extra casing, filled with magnesia, is put around the outside pipe between these decks. Above the gun deck, or, where there is no gun deck, above the protective deck, and extending some distance above the upper deck, an extra casing, leaving a 6-inch air space, is put around the outside pipe. An umbrella or hood, worked around the smoke pipe above this casing and a sufficient distance from it, covers this opening and prevents water from getting into the air space. By this arrangement, some of the heated air in the space surrounding the smoke pipe and

between the protective and upper decks can escape to the atmosphere, far enough above the smoke pipe hatch coaming to clear the heads of men.

The top of the inner pipe is somewhat higher than the outer casing, and is fitted with a hood which extends down and over the outer casing. The latter stops within about six inches of the bottom of the hood, so as to leave sufficient opening for the escape of the heated air. Both pipe and casing are strongly stayed to each other to make a rigid smoke pipe. At intervals, bands are riveted to the outer casing, to which shackle bolts for the *smoke pipe guys* are secured. With the high pipes now generally used, three rows of guys are fitted, one from the hood at the top of the pipe, another about 30 feet above the upper deck, and another about half way between these. The guys consist, usually, of wire rope, fitted with turn buckles, by which the tension can be adjusted, and are secured to the sides and other parts of the ship so as to stay the pipe completely. The turn buckles must be adjusted after the pipe has become thoroughly heated, the guys being slack before fires are started.

A round iron ring is secured to the smoke pipe near the top, for use in hooking painters' slings, and an iron ladder, running to the top of the pipe, is secured to its forward side. The top end of the inner pipe is finished with a half round band, and across the opening of the pipe, arched crossbars are secured to support a canvass cover, when needed. The lower end of this cover is secured to eye-bolts fitted around near the outer rim of the upper hood. These covers should be kept on the pipes not in use.

Surrounding the smoke pipes and at some distance from them, the *smoke pipe hatch* is built, extending from the protective deck to some feet above the upper deck. This space is frequently called the *uptake room,* access to it and from it to the smoke pipe being obtained through suitable doors. In ships where the top of the fire room is open to the atmosphere, the hatch is called the *fire room hatch.*

Armor Bars and Gratings.—These are fitted inside of the smoke pipes, in the smoke pipe and engine room hatches, and in the ventilators, and take the place of the protective deck which has been omitted at these places. They give the required protection from shot and shell to the machinery below, while admitting some of the fresh air necessary for respiration, ventilation and supplying

the fires. These bars are thin and made deep for strength, and are supported in sockets in the protective deck, except inside the smoke pipe, as already explained, and in the ventilators. In the latter, they are usually in the form of hinged gratings, which can be raised and lowered from the engine and fire rooms. Similar gratings are fitted over those parts of the hatches through which are led the ladders from below.

Ventilators.—These are simply large tubes which run from the fire and engine rooms through the various decks into the atmosphere, well above the highest surrounding parts of the ship. Large *cowls,* which can be turned by suitable gear from the upper deck and sometimes also from below, are fitted on top of the ventilators, the operation of turning them to suit the wind being called *trimming ventilators.* Ladders are often fitted on the inside of large ventilators as a means of egress.

Where the forced draft is on the closed fire room system, the lower end of each ventilator is provided with a hinged door, which is closed and locked when the air pressure is put on the fire room. Where the ventilators are used only as air supply ducts for the fire room blowers, as on a few of our ships, the bottom of the ventilator connects to the inlet of the blower. As there is then no direct admission of air to the fire room, the lower door is omitted. Under this condition, the blowers must be run practically all the time, both for ventilation and for the fires.

Some of the ventilators are also used as *ash hoists,* being fitted with vertical straps to guide the ash bucket, and provided near the top with a pulley through which the whip from the *ash hoisting engine* is led. A door is cut in the ventilator on the deck from which ashes are dumped, suitable rails and a trolley carrying the bucket to the ash chute at the ship's side. Where the closed fire room system of draft is used, the ash hoist is fitted with a hinged door on the deck from which ashes are dumped. By closing this door when the bucket is descending, the lower one being open, and vice versa when the bucket is going up, the ash hoist need never be entirely open to the outside air. A small slot is cut in the upper door for the ash whip.

Bells with pulls in the fire room and on deck, a speaking tube, and the ash hoisting engine, which is provided with suitable reversing gear and adjustable safety gear to prevent over-winding and to stop the engine when the bucket reaches the fire room floor, complete the equipment of the ash hoists.

CHAPTER X.

STEAM PIPES AND ATTACHMENTS.

We will now explain how the steam from the boiler is led to the main and other engines, how the pipes which do this are fitted, and show what attachments are necessary for their safe use.

The various arrangements of piping adopted for different ships can be explained in general only. One of the first duties of the engineer officers is to familiarize themselves thoroughly with the lead of steam and other pipes, by actual inspection and by a study of the drawings furnished each ship, and to see that their subordinates acquire a like knowledge.

The steam piping of each ship consists of the *main* and *auxiliary* systems, the former to supply the main engines only, and the latter, by means of numerous branches, all auxiliary engines. In order that either system may be used, in case of leaks or other accident to one of them, the two systems are connected by a cross pipe with a valve at each end.

In ships having a central, fore-and-aft bulkhead, there is a main, and, usually, an auxiliary system on each side throughout the length of the boiler compartments. Steam from the boilers is generally led by branch pipes directly to each system through separate stop valves on each boiler, each system receiving steam direct from the boilers. In the "Virginia," "Pennsylvania," and later classes of ships, the main steam pipe system gets steam indirectly from the boilers. The group of boilers in each compartment is connected by branches to the auxiliary system. In each compartment there is a short connection between the auxiliary and main systems, with a stop valve in the connecting pipe and another one in the main steam pipe just forward of this junction.

The two main systems end at the main stop valves, just abaft the engine room bulkhead, and are there connected by an athwartship pipe, in which is a stop valve which can be worked from either engine room. Abaft these stop valves are the main engine throttle valves, through which steam is admitted to

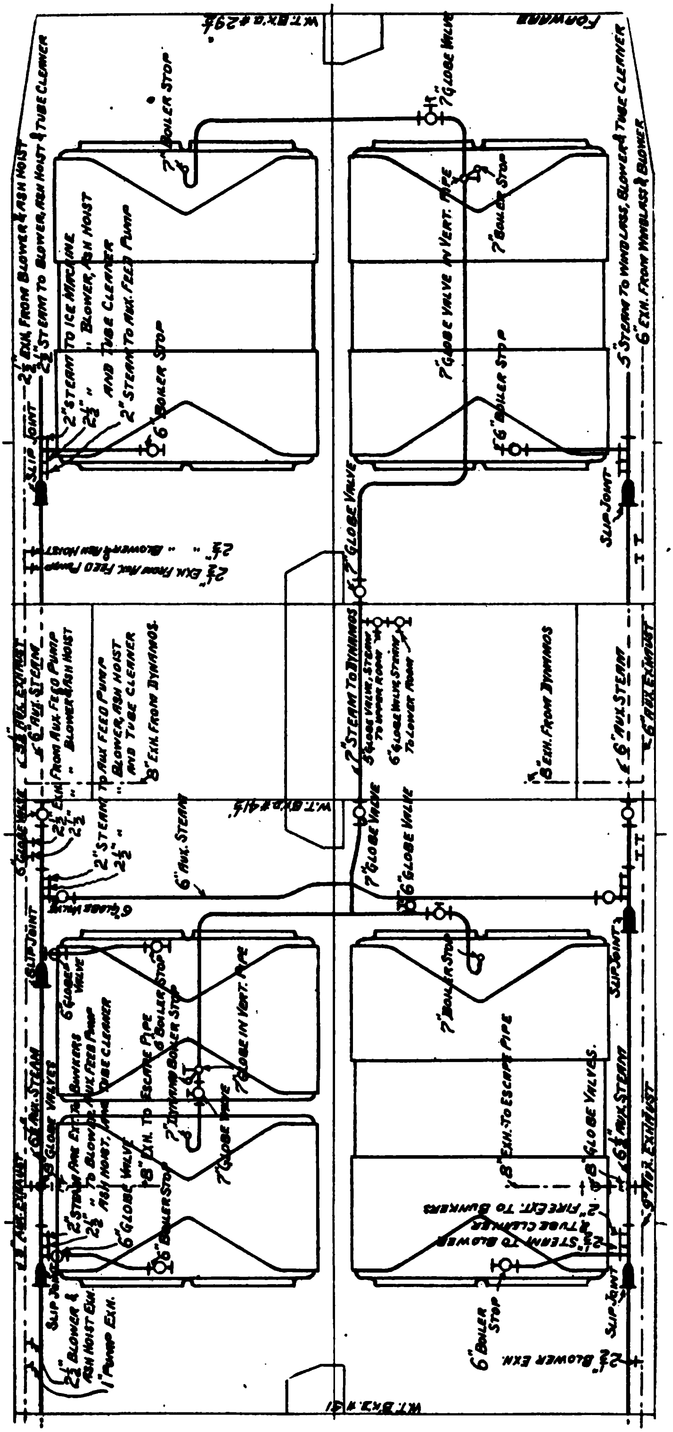

FORWARD
SLIP JOINT
7" BOILER STOP
7" GLOBE VALVE
6" BOILER STOP
7" GLOBE VALVE IN VERT. PIPE
7" STEAM TO DYNAMOS
8" EXH. FROM DYNAMOS
6" AUX. STEAM
6" AUX. EXHAUST
6" GLOBE VALVE
2" STEAM TO ICE MACHINE
2½" STEAM TO BLOWER, ASH HOIST & TUBE CLEANER
2" STEAM TO AUX. FEED PUMP
5" STEAM TO WINDLASS, BLOWER & TUBE CLEANER
6" EXH. FROM WINDLASS & BLOWER
8" EXH. TO ESCAPE PIPE
6" GLOBE VALVES
2½" BLOWER EXH.
2" FIRE EXT. TO BUNKERS
1" PUMP EXH.

FIG. 35.

the engines. In case of accident to the main steam pipe on one side, the main engines can, therefore, be run by the main system on the other side, by closing the main stop valve on the injured side and opening the communicating valve in the athwartship pipe.

The two auxiliary systems are continued on each side to some distance abaft the engines, where they are connected by an athwartship pipe. In some ships, especially smaller ones, only one auxiliary system is fitted. Extensions lead to auxiliary machinery forward of the forward boiler compartment. Separate steam pipes, with separate boiler stop valves, are generally fitted for the dynamo engines.

Fig. 35 shows the lead of the auxiliary steam and exhaust pipes, and the special dynamo pipes in the boiler compartments of the "Kearsarge" and "Kentucky," the main steam pipes and stop valves being omitted for clearness. There are three double-ended and two single-ended boilers, the upper and lower dynamo rooms being between the forward and the after boiler compartments. Owing to the large electric power installation, on account of the electric turret-turning and other ordnance gear, as well as many of the auxiliaries, the dynamo steam pipe is larger than the auxiliary steam pipe.

The two auxiliary systems are connected to each other by an athwartship pipe in the forward part of the after boiler compartment, a stop valve being fitted at each end. In the starboard after boiler compartment, in the forward fire room, there is a 6-inch stop valve connecting the auxiliary and dynamo steam pipes. Slip joints are shown in the straight auxiliary steam pipe, while the dynamo pipe is fitted with bends.

The auxiliary exhaust systems are run outboard of the steam pipes and connect the exhaust from all auxiliary engines.

With separate steam pipes to the dynamo engines, the electric lights may still be used in case of accident to or overhauling of the auxiliary steam pipes, and the supply of steam to the dynamos is independent of that for the many other auxiliary engines.

Reducing valves are fitted in the dynamo pipes, in the case of these two ships, close to the boilers, the dynamo engines being designed for a steam pressure of 110 pounds, while that of the boilers is 180 pounds per square inch. In other ships, the reduc-

ing valves are generally placed near the separator which is fitted close to the dynamo engines.

The auxiliary steam and exhaust pipes are continued into the main engine rooms, and branches lead to the various auxiliaries there.

Fitting of Steam Pipes.—The various lengths or sections of pipes which make up a line of piping are bolted together by means of flanges or slip joints, secured to the ends of each length. The pipes are so led and flanges so placed that each section can be readily taken down for renewal or repair and the joints be easily overhauled.

Special care is used in leading the pipes to avoid, as much as possible, downward bends or *pockets,* in which condensed steam can accumulate, so that the dangerous results of *water hammer* (see below) may be prevented. Where it is not possible to avoid accumulation, ample drain cocks or valves are fitted.

In order that the sections of pipes may expand and contract freely with the variations of temperature, movable joints, called *slip joints* (see below) frequently take the place of fixed flanged joints. Where slip joints cannot be fitted, the pipes are led with ample bends, the elasticity of the pipe at the bend allowing the necessary movement.

Wherever pipes pass through water-tight bulkheads and decks, stuffing-boxes are fitted, or flanges are fitted and secured direct to the bulkhead or deck. Holes for pipes through wooden decks have a brass or copper thimble or sleeve, made water-tight, and which extends at least three inches above the deck. The pipes are always led so that no angle or T-iron of bulkheads will have to be cut.

Branches from a main are now always led from the top or side of the pipe, never from the bottom. All such branches, both in the auxiliary steam and exhaust pipes, have. stop valves at the junction and at the end, to prevent their filling with condensed steam.

As *exhaust pipes* conduct steam, although of a much lower temperature, they are fitted like live *steam pipes.*

To reduce loss of heat by radiation, all steam and exhaust pipes, their flanges and valves, are clothed with non-conducting material, like sectional magnesia covering, which can be readily

removed without injury. A canvas covering, well painted, finishes the outside. In the engine room and other exposed places, an additional covering of Russia sheet iron is put on with brass bands.

Flange Joints.—These joints, especially with high pressure steam, are a source of constant trouble and the loss of much fresh water, unless great care is taken in fitting them. The first requisite for a tight joint, the parts of which have been properly designed for strength, is that the faces of the two flanges shall be parallel, smooth, and not too far apart, and the second, that the intervening gasket shall be soft enough to fill any slight inequalities in the flange faces, and yet be able to withstand the high temperature and pressure of steam. The generous fitting of expansion joints or bends helps to keep flange joints tight.

Many devices and many kinds of gaskets have been tried. The practice of the Bureau of Steam Engineering has been, for many years, to require all flanges to be faced and grooved. Of the gaskets allowed, some form of asbesto-metallic sheet packing or corrugated soft copper are recent types. Corrugated copper gaskets are the only ones permitted for the joints in steam pipes on the latest large ships. The thickness of the copper gasket for a good joint under high pressure (250 to 300 pounds per square inch) is usually about No. 26 B. W. G. The thinner the gasket, when the first requisite for a tight joint has been secured, the better the joint, as there is less liability of the gasket blowing out, and if copper is used, less opportunity for corrosion with steel pipes.

In order to appreciate the force of this last remark, we will take up the materials of which pipes and flanges are made.

Materials of Pipes, Fittings and Flanges.—The steam and exhaust pipes of the "Kearsarge" and "Kentucky" are of copper, seamless drawn for diameters of 6 inches and less, and brazed for larger diameters. Where these pipes are 9 inches in diameter or larger, they are strengthened by $\frac{1}{8}$-inch steel bands, spaced 6 inches apart, and each fitted with tension screws so that it can be set up. In ships of later design, lap-welded mild steel pipes have replaced copper ones above 6 inches in diameter. In more recent years, say since 1899, all steam pipes above two inches in diameter have been made of mild steel, generally seamless-drawn.

No screw joints are allowed in steel steam piping. Where the change in the direction of the piping is too abrupt, or where a branch is led off at a small angle, various cast *fittings* are used to which the straight pipes are bolted. These fittings consist of *elbows* for very short bends, *T*'s for right angle changes in direction, and *Y*'s for acute-angled branches, and are made of composition or steel for steel piping, and of composition for copper pipes. Y's and elbows are shown in Fig. 37.

The flanges of copper pipes are of composition brazed on, the end of the pipe being expanded into a recess in the face of the flange, see C, Fig. 36. The flanges of steel steam pipes are either stamped or forged of mild steel of the same quality as that of the pipes; the pipe is either welded to the flange, or else rolled into it and beaded over into a recess, as before.

With a thick copper gasket between the two steel flanges, a comparatively large surface of copper, exposed to steam and impure or brackish water, acts on the adjacent steel, the latter being quickly corroded. This happened in the steam pipe joints of the British warships "Powerful" and "Amphitrite," where, after a few months' use, the steel faces were so much corroded that the joints could not be kept tight. The copper gaskets used were at least 3-64 inch thick, or about ten times as thick as specified above. In their later practice, the copper gasket was omitted, the faces of flanges being carefully fitted by hand scraping, and the joint made by a thin wash or paint of red lead and oil. This made a tight but very expensive joint.

Expansion Joints.—The linear expansion of copper for 1° F. is about twice that of steel, the exact figures for 1° rise in temperature and for 1 foot of length being .000115 inch for copper, and .0000763 inch for steel, according to Clark. Suppose that a straight copper steam pipe between two bulkheads, 30 feet apart, the pipe being bolted by a flange at each end, is a good fit at 62° F. If the working pressure in the pipe is 180 pounds per square inch, by gage, the corresponding temperature is about 379° F., a rise of 317°. The linear expansion under these conditions would be $30 \times .000115 \times 317 = 1.094$, or about $1\frac{3}{32}$ inches, and it would be impossible to keep the joint between the pipe and the flanges tight, even if a more serious accident, such as rupture of the pipe, did not happen.

To allow this expansion and contraction to take place freely, without injury to the pipes or joints, all steam, exhaust, and feed pipes are fitted with *expansion* or *slip joints,* wherever they may be necessary, and where the simpler bends cannot be put in. It will be observed that feed pipes must be similarly fitted, as they are often subject to a change of temperature of 150° F. or more.

Fig. 36 shows a slip joint as fitted on the "Indiana," which will give the principle on which they are constructed. The details may vary, but there must be a stuffing-box, a follower, and an entering pipe, all, generally, of composition. The stuffing-box and entering pipe have flanges by which the connections are made to the pipe main.

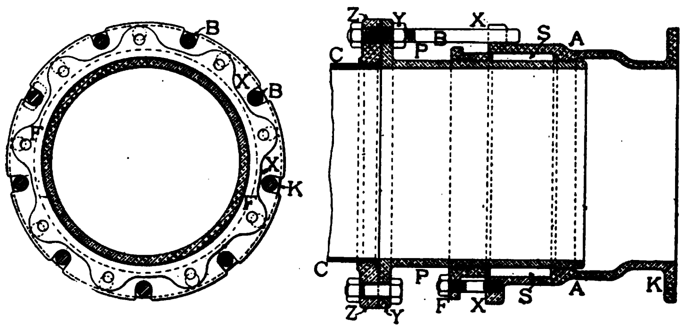


FIG. 36.

A is the stuffing-box casting, F, the follower, with its studs and nuts, by which the metallic packing in S is set up and by which the joint around the sliding pipe P is made steam-tight. One end of the copper steam pipe C is shown with its flange Z bolted to the flange Y on P; the other end of the main is similarly flanged and bolted to the flange K, at the base of A. To prevent the entering pipe from moving too much in the stuffing-box, square-headed stop bolts B, B, are fitted between the two flanges X and Y. The nuts on the ends of these bolts are not set up against Z, but some distance from it to allow the required motion.

In order that the pipes may move in a straight line, and be prevented from pulling apart, recent practice requires that the two parts of a section of piping, united by a slip joint, shall be

anchored to each other. Steel rods, generally two, are run between and bolted to the castings of consecutive slip joints, or between a bulkhead and one casting. Fig. 37 shows a method of anchoring adopted on the "Cincinnati." The method of supporting the weight of pipes P and fittings from the deck is also shown, as well as a Y fitting at C, and two elbow branches at B, B. Turnbuckles are fitted in some of the anchor rods A, to allow for adjustment in each compartment. V is a bulkhead stop valve. S, S are the slip joints.

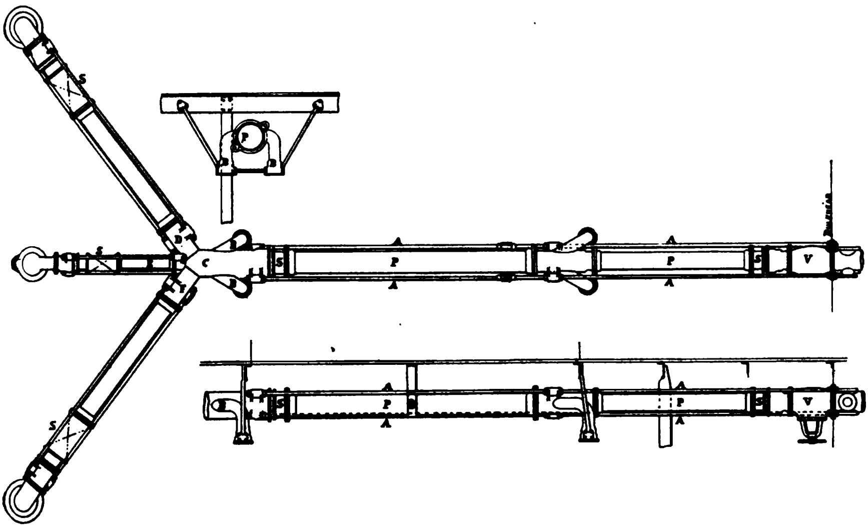


FIG. 37.

Serious accidents have happened through the pulling out of steam pipes from the stuffing-box of a slip joint, unprovided with proper stops and anchors. The most serious one occurred on the German battleship "Brandenburg" in 1893. A ten-foot length of pipe between the separator and one of the main engines pulled out on the full power trial, and allowed the steam from twelve boilers to rush into both engine rooms, killing 39 men outright and fatally burning 9 more. There were no automatic stop valves in the steam pipe.

Slip joints are also fitted in lighter ships for the purpose of preventing undue strain on steam piping due to motion of the hull when rolling.

Water Hammer.—This name is given to the action which takes place when steam is admitted into a pipe containing some water. It may be evident by a hammering noise and leaks in flanges or joints, or by heavy shocks and rupture of the pipes. Many serious accidents have occurred from this cause, an example of the effect of which is shown by the piece of the "Concord's" main steam pipe in the model room.

To prevent accidents of this kind, ample provision for drainage is made, as mentioned above, and great care must be used to see that every pipe, into which steam is to be admitted, is thoroughly drained before the stop valves to that section of piping are opened. As an additional precaution, the stop valve, or the by-pass valve, if fitted, must be opened very slowly and a little at a time, until it is evident that the pipe is warm and clear of water. It may be mentioned, that nearly all accidents of this kind have occurred while connecting boilers to cold steam-pipes. Water entrained with the steam, as during priming, will make itself evident at the engines rather than in the steam pipes.

Steam Separator.—Between the main steam pipes and each main engine, and between the dynamo steam pipes and the dynamo engines, a *separator* is fitted in each engine room and in the dynamo room. This is a mechanical contrivance through which the steam passes on its way to the engine, and in which most of the water in the steam or condensed in the pipes is separated from the steam. This separation is effected simply by an abrupt change in the direction of the current of steam and water, or by centrifugal action in addition.

The ordinary diaphragm separator, which is often fitted, consists of a closed cylinder, with openings for the entering and leaving steam near the top. A vertical plate, reaching from the top to some distance from the bottom, separates the cylinder into two parts. The entering steam strikes the diaphragm, then passes down around its lower end, and upwards and out of the other opening into the engine side of the steam pipe. The heavier water, which has been separated by the two changes in direction, drops to the bottom of the cylinder. This part of the separator is fitted with a gage glass, a drain cock, and a discharge pipe, the latter leading to a trap. The water level should always be kept above the bottom of the glass, to prevent the waste of live steam in case

the trap gets out of order. The drain cock opens directly into the bilge.

One form of centrifugal separator, the Stratton, is shown by Fig. 38. Here the diaphragm is replaced by a central pipe which extends from the top down to about half the height of the outside casing. The wet steam enters at the right of the figure and passes around the central pipe in a spiral direction, as shown, the heavier particles of water being thrown, by centrifugal action, against the sides of the casing. The water runs down into the reservoir below, and the dry steam, after reaching the bottom of the central pipe, passes into it and out of the separator by the upper opening at the left, and thence to the engines. The reservoir is fitted with the usual automatic gage glass and a drain pipe at the bottom.

FIG. 38.

It was found in practice that, when steam of high pressure was used, the rotary motion imparted to the water as it separated was continued, in some cases, especially where the separator was short, down to the bottom of the reservoir. This resulted in a layer of water against the sides of the reservoir and a space, filled with steam, in the center. The gage glass would show full and, on opening the drain, steam would be blown out. To remedy this defect, by breaking up the whirling motion of the water, wings or plates are put in the reservoir, as shown, standing at an acute angle to the course of the current. These cause the water to settle solidly towards the bottom, and the gage glass will give the correct height at all times.

Drain Pipes and Traps.—As already stated, *all* places where condensed steam can accumulate are provided with ample drain pipes with cocks or valves. To prevent the waste of fresh water, all drain pipes are led into automatic *traps*, which discharge, generally, into the feed tanks or condensers. The drain cocks or valves are attached, where possible, directly to the part to be drained in order to avoid the use of intermediate piping and thus to ensure greater safety. The handles of drain cocks point downwards when the cock is closed.

The steam traps used in our navy are *float* and *expansion* traps, the latter being used only to drain the heater system of piping.

A float trap consists essentially of a chamber to receive a certain quantity of water from the drains; an inlet, which is under the steam pressure of the pipe or other part to be drained; an outlet, which is under the lower pressure of the feed tank or other place to which the water is to be discharged; and a valve, which automatically opens connection between the inlet and outlet whenever a certain quantity of water has accumulated in the trap. When this takes place, water will be blown out of the trap by the inlet pressure until the valve closes.

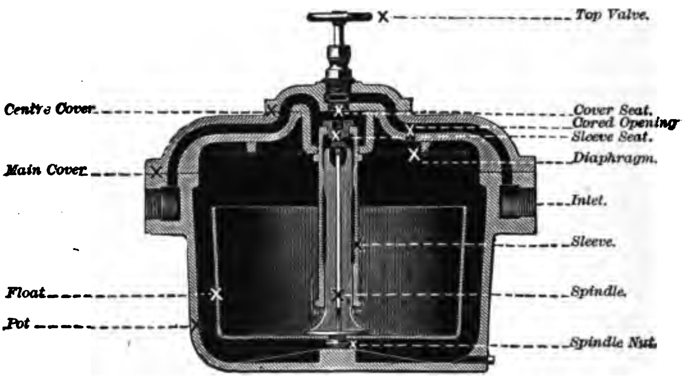


FIG. 39.

Float Traps.—Fig. 39 shows the Nason steam trap in section. A cast iron reservoir or pot, closed by a cover in which are two cored passages, contains a float which is fitted with a central spindle. A sleeve, screwed into the under side of the cover, surrounds the spindle and acts as a guide for it and the float, the latter having a short vertical motion. The top of the float spindle is ground flat and its upward movement is stopped by a valve seat of bronze, which is screwed into the top of the sleeve. The flat top of the spindle acts, therefore, as a discharge valve.

The cored passage marked "inlet" has two openings, one of which is always open to the reservoir, and the other, in the top of the cover, is fitted with a valve. The latter opens or closes communication between the inlet and outlet passages of the trap, and serves as a by-pass valve when any large quantity of air or

water is to be blown through direct, without going through the reservoir. In the larger sizes of traps, the main cover has a small central one on top, the removal of which gives access to the working parts without disturbing the large cover.

The trap must always be placed below the point from which the water of condensation is received. The automatic action of the trap, with the top valve closed, is then as follows: The water enters through the cored opening into the reservoir, a diaphragm directing it around the outside of the float, so that it will fall to the bottom of the pot. As the water rises in the latter, it first lifts the float and thus closes the discharge valve, and then, after reaching the top of the float, flows into it. When nearly full, the weight of the contained water overcomes the buoyancy of the float, and the latter drops to the bottom and thus opens the discharge valve. The steam pressure acting on the surface of the water then forces it up through the sleeve and discharge valve into the outlet passage. When the weight of water in the float has been sufficiently reduced, the float will rise again and close the valve, and the operation will be repeated. When the trap is in working order, the automatic actions of blowing out and closing of the valve are frequent and distinctly audible. When these are not heard, the trap should be blown through with the by-pass valve. If this is not sufficient, the trap should be opened and overhauled. The trap can be drained by opening the small screw plug in the bottom of the pot. The raised stop at the bottom of the outside chamber prevents the bucket from sinking too far, and allows a small space at the bottom for the collection of any sediment.

The size of the discharge valve depends on the range of steam pressure used, the standard opening being for pressures between 20 and 70 pounds per square inch. For higher pressures, the opening is smaller and certain changes are made to strengthen the joints, the trap for pressures above 70 pounds being of the Nason "sidelug" pattern.

Fig. 40 shows the Kieley, another form of float trap. In the cover on the front of the casting are three holes, the central one, shown in the figure, being the outlet, and another one, the inlet. The third one is closed by a valve which is used as a by-pass, when the trap is to be blown through. The inlet opens directly

into the chamber, while the outlet extends inward and its opening is controlled by the vertical valve. The lower end of the stem of this valve is pivoted to the bottom of a float, which in turn is pivoted to the cover. Around the valve stem there is a sleeve, secured to the outlet projection, the bottom of which is open and extends to within a short distance from the bottom of the float. As the float is so proportioned that there is normally enough water in it to cover the end of the sleeve, the valve is always protected by this water seal. These traps are made to suit different ranges of pressures, the size of the valve decreasing

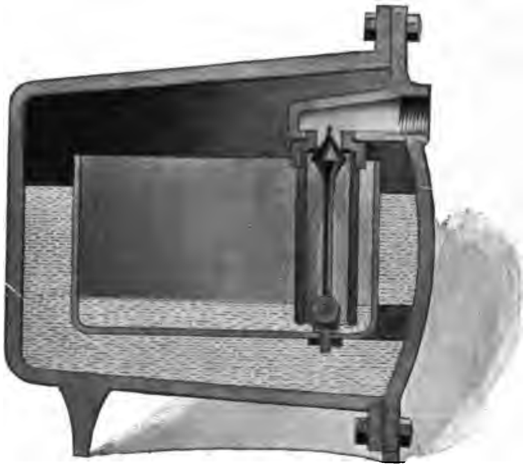


FIG. 40.

as the pressure is increased. An air cock is fitted to the top of the chamber. The action of the trap is similar to that of the one described above.

Expansion Traps.—Fig. 41 shows one form of expansion trap, the "Columbia." In these, the valve is worked through levers by the expansion and contraction of the parts composing the trap, this valve, as before, opening or closing the connection between the inlet and outlet. In the Columbia trap, the valve C is open so long as the cooler water of condensation is near the valve; when this has been blown out and steam reaches the valve, the expansion of the brass inlet pipe, which is the upper one, shown in white in the figure, acting through the upright lever on the valve stem, closes C. To prevent damage to the brass tube

or to the valve by over-expansion, the spring D is placed between the lever and valve stem. Its tension is such that it will just balance the force exerted to move and seat the valve, any additional force being expended in compressing the spring. The fulcrum of the lever, at one end of the small rod below the inlet pipe, can be adjusted by the nuts at the other end. By means of the lever A, connected to the head of the valve stem, the trap can be blown through by hand. As the valve is always open when the trap is cold, it is self-draining. The opening of the valve is of the same size as the inlet, thus allowing a rapid discharge of the water. If desired, a water gage can be fitted to the tapped holes closed by the plugs B′, B′.

All traps are fitted with pipes and valves by means of which the trap can be shut off when it is necessary to overhaul it. The

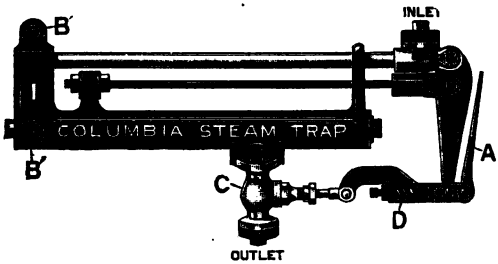


FIG. 41.

covers or plugs, provided for convenience in overhauling, must be so fitted that the main pipe connections will not have to be broken. Traps should be examined and cleaned occasionally. To prevent a trap from becoming air-bound, a common occurrence, the by-pass valve must be used at intervals.

Pressure Reducing and Regulating Valves.—Wherever it is economical, necessary, or desirable to use a lower steam pressure than that in the boilers, as in most auxiliary engines, in steam jackets, and in the heating system, or where it is advisable to keep a steady lower steam pressure, independent of the fluctuations of the higher pressure in the boilers, as in dynamo engines, *reducing* valves are fitted in the steam pipes leading to the auxiliary engine. These valves can be set to any desired *delivery* pressure, within the limits of the given valve, after which the valve automatically maintains this pressure, regardless of the changes in pressure on the supply side.

Foster Reducing Valve.—Figs. 42 and 43 show the Foster pressure reducing valve, extensively used in our navy. Fig. 42 is a quarter section of the "Class W" valve for sizes 2½ inches and larger, and Fig. 43, a sectional view of the same valve to a larger scale. In our navy, the valves are secured to the steam pipe by flanges only, the screw threads shown at B being, therefore, omitted, and all castings are of composition.

The principle on which the valve works is that of *wire-drawing* or *throttling* the steam, i. e., causing a lower pressure on the

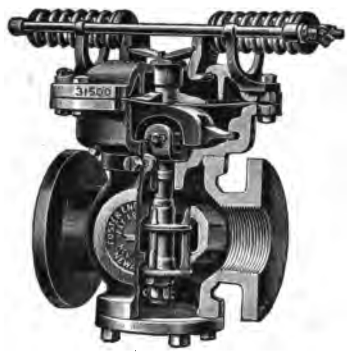


FIG. 42.

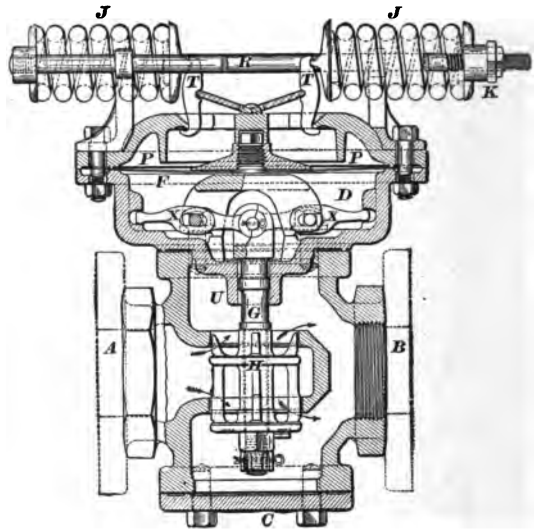


FIG. 43.

discharge side of the valve by permitting only a certain quantity of steam to enter from the other or supply side, through a restricted or throttled opening of that valve. The valve is controlled and operated by the movement of a diaphragm opposed to the action of springs, the tension of which is adjusted to the delivery pressure to be maintained.

Steam enters at A under boiler pressure and, flowing through the partially opened valve H, leaves at B. If it is desired to have a right-angled connection between the inlet and outlet, B is closed and C opened. Above the valve chamber U is the diaphragm chamber D, the top of which is formed by one or two flexible metal discs or *diaphragms* F. Steam from U enters D

through the small passage or *port* in the lower part of this chamber (the bolt which opens and closes this port is shown at the break in Fig. 42, and the port, by the black line just above the bolt), and causes F to rise, and, by means of the saddle, the levers X and valve stem G, to close the double valve H. This closing is resisted by the springs J, by means of T and the two small links, the latter bearing down on the large screw guard which secures the diaphragm F to the saddle. The outer rim of the diaphragm is secured by the upper bonnet which has a central opening, so that the top of F is open to the atmosphere.

We have then a valve suspended by a flexible disc, on one side of which acts the delivery steam pressure, and on the other, the tension of the springs, which have been adjusted to give a desired pressure. So long as the delivery pressure is equal to that for which the springs have been set, the valve remains in equilibrium, being partially open. If, from any cause, the delivery pressure increases, the diaphragm will be forced up and lift the valve, tending to close it, until the pressure drops sufficiently to restore the equilibrium. If the delivery pressure falls, the springs force the diaphragm and valve down, tending to open it, until equilibrium is again established.

The valve H is double-seated and closes upwards. The valve stem G is guided by a shoulder in which are grooves for water packing; its upper end is pivoted to the levers X, which in turn are pivoted by a pin and slot to the saddle D. This arrangement of levers increases the small movement of the diaphragm to a larger one at the valve. On valves larger than 8 inches, the levers give the valve a motion of from 4 and 5 to 1. In a 10-inch valve, the extreme movement or deflection of the diaphragm above and below the mean line is $\frac{5}{32}$ inch each way, and the valve has a movement of $\frac{20}{32}$ or $\frac{5}{8}$ inch each way. This small movement of the diaphragm, which for this size of valve would be 12 inches in diameter, is well within the limits of its flexibility. To prevent the diaphragm from exceeding the limits of its elasticity, the safety ring P is provided. Valves of and below 2 inches are not fitted with levers X, the stem pivoting in the saddle directly.

The toggle arrangement, consisting of T and the two small links, provides a compensation for the increasing power of the springs as they are compressed while working, as well as for

the increasing resistance of the diaphragm. The tension of the springs, as set by the adjusting nut K, is, therefore, constant on the diaphragm. By increasing the tension on the springs, the delivery pressure is increased. The port hole, through which the delivery steam enters F, may be closed partly or entirely by the port screw bolt from the outside. In small valves, a slot in the head of this bolt shows, by its deviation from the vertical, the amount that the port is closed; in larger valves, the bolt is turned to the right as far as it will go. Where the diaphragm, which is made of saw steel or phosphor bronze, consists of more than one plate, the upper one is either perforated or slotted radially, in order to prevent any accumulation of pressure of steam, by leakage, between the plates. A steam gage is fitted on or near the delivery side of each reducing valve.

These valves, although they will work in any position, should if possible, be fitted to a *horizontal* steam pipe and with the diaphragm facing up. For capstan, windlass, steering and other engines, which are used intermittently, the valves must be so fitted, because, if inverted, the condensed steam, which will accumulate in the diaphragm chamber, will cause a sluggish movement of the valve, and prevent a quick response when there is a sudden increase in the volume of the discharge.

The next best way is to fit the valve to a horizontal pipe with the diaphragm in a vertical position, and the bolt, which opens and closes the small port between U and D, *pointing down.* It will be seen that, if so fitted, only a small quantity of condensed steam can remain in the diaphragm chamber, as most of it will drain into the valve chamber through the port. In this position, the valve H will not be suspended freely, but will bear on the lower side with more or less friction and consequent wear. When absolutely necessary, valves, two inches and smaller in diameter, may be fitted to a vertical steam pipe, but always with the steam *ascending* through the regulator, unless an efficient strainer is fitted on the inlet to keep out scale, grit, etc.

A stop valve must always be fitted on the inlet side of the regulator. This valve must be opened *wide* while the regulator is in use, and closed when no steam is required beyond the regulator. When the piping system of a vessel is to be tested by hydraulic pressure, the port between U and D of all regulators

on the pipes to be tested must be closed, and the small screw plug in the diaphragm chamber (see Fig. 42) opened, to prevent the bulging of the diaphragm by excessive pressure.

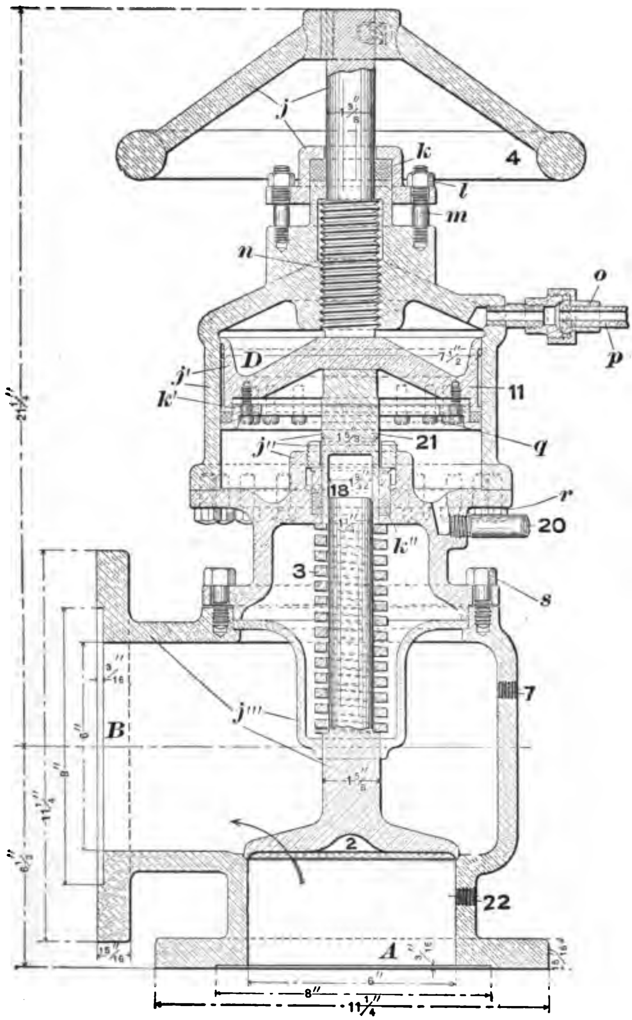


FIG. 44.

An adaptation of the diaphragm control of a valve is used with the Foster reducing, non-return, automatic and emergency stop valve, and is fitted on the "Hopkins" and other destroyers. Fig.

44 shows a section of the top valve on the boiler, and Fig. 45, a section of the pilot valve, by which one or more stop valves are controlled, either automatically or by hand, in an emergency.

Foster Stop Valve.—This part of the above device is bolted to the boiler, steam entering at A, Fig. 44, and passing into the steam pipe at B. Valve 2 is held against its seat by the spring 3, and opens only when the pressure in the boiler exceeds the power of the spring. Since this is an ordinary valve, and the

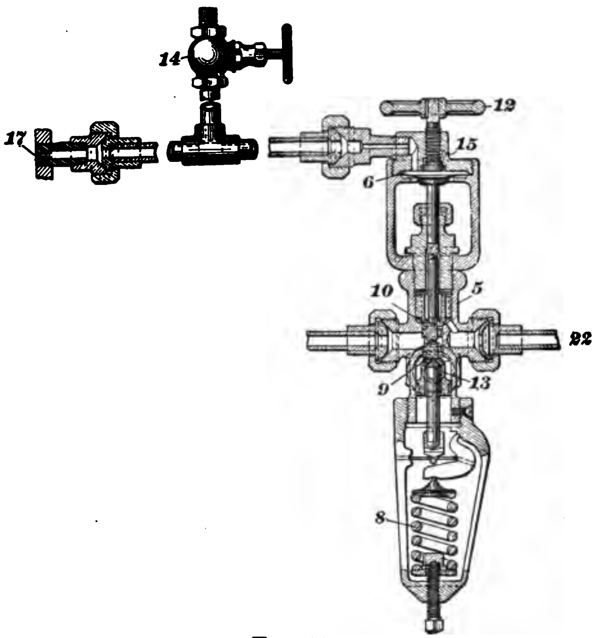


FIG. 45.

spring can be of any required resistance, the valve will open only slightly, as explained under "Safety Valves." The steam will, therefore, be wire-drawn and its pressure in B reduced below that in the boiler.

In case of a bad leak in the *boiler*, valve 2 will close almost instantly, and shut off the injured boiler. To make it close automatically or at will, when there is a rupture or other serious leak in the *steam pipe* system, a steam cylinder and piston, the rod of which is separate from the stem of valve 2, are added, as shown. A hand wheel 4 is fitted above this, by which the piston and its

rod can be pushed down on the valve stem and thus close valve 2 firmly, as in an ordinary stop valve. The cylinder has a steam pipe connection at *p* to the chamber D above the piston, and a pipe connection below at 20 for the free escape of air, and, incidentally, of any steam which may leak past the piston.

Foster Pilot Valve.—Pipe *p*, Fig. 44, is connected to the pilot valve, Fig. 45, on the side opposite to pipe 22, the latter being connected to the boiler. The pilot valve, which may be placed near the stop valve or elsewhere, consists of spring 8 below, a casting 5, which contains two valves opening in opposite directions, and a hollow casting above, which contains the diaphragm chamber 6. The latter is connected by pipe 17 to the steam pipe system or to the outlet side of the stop valve casing at 7, Fig. 44. On our destroyers, the pilot valve is secured to the boiler front, and branches are led from pipe 17 to the engine and fire rooms, and on deck, each branch, as at 14, being provided with a ¼-inch stop valve opening into the atmosphere. By means of any one of these valves, the pressure in the steam pipe system can be lowered at will.

Any load put on the spring 8 by the adjusting screw below will be communicated, by means of the abutting rods and valves, to the diaphragm, and be resisted by the steam pressure in 6. If the spring is adjusted to say 150 pounds, then, so long as the pressure in 6 and, therefore, in the steam pipe system, is over 150 pounds, valve 10 will remain closed, valve 9 open, and D in communication with the atmosphere through pipe *p* and the exhaust at 13. But, if the pressure in the pipe system drops to or below 150 pounds, spring 8 pushes up and closes valve 9 and opens valve 10, thereby admitting the boiler pressure (which must, of course, be higher than 150 pounds), from 22, through the little port, into pipe at *p* and so into D. The piston in D being larger in area than valve 2, instantly forces the latter against its seat and holds it closed until the pressure is relieved.

To open valve 2, the hand wheel 12 on the pilot valve is screwed down until valve 10 is closed, thus shutting off the steam from D and opening valve 9. The latter then allows the steam in D to escape through 13 into the atmosphere, and, when the pressure in the boiler is greater than in the steam pipes, valve 2 will open. If, through carelessness, the stem of the hand wheel

12 is not screwed back from the diaphragm, after everything is ready for operation again, there will be a leakage of steam from the tell-tale opening 15, which can be stopped only by bringing the shoulder on the stem into proper position against it.

The above device for shutting off all boilers, either automatically or at will, is very ingenious and effective; but, owing to the

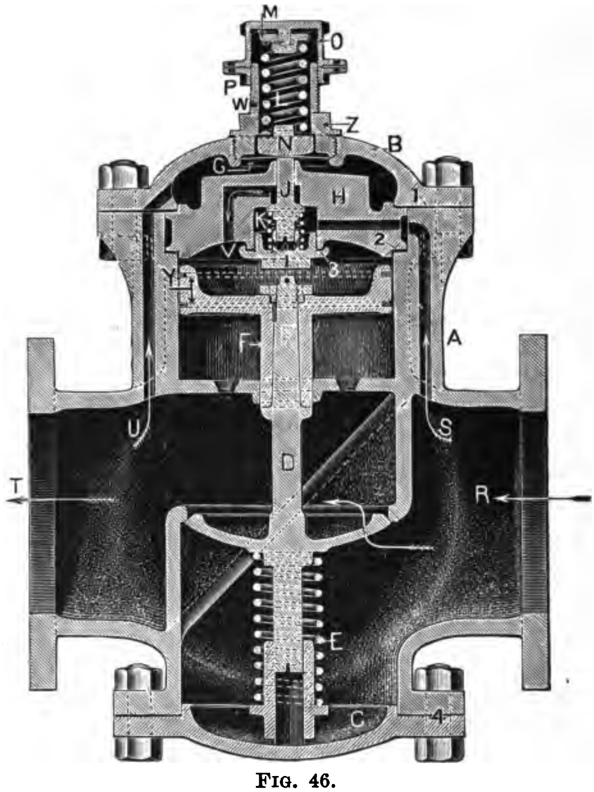


FIG. 46.

number and length of the small unprotected pipes, necessary to connect all the pilot and their stop valves and the several emergency stations, the boilers may be shut off by the breaking of one of these small pipes while men are working around the fire or engine rooms. Such an accident, otherwise unimportant, would render the whole system inoperative. Great care should, therefore, be used to lead all of these small pipes so that they will be protected from injury as much as possible.

Leslie Valve.—Fig. 46 is a sectional view of the Leslie pressure regulating valve, Class E, which has come into use recently on our ships. These valves are of the same construction for all sizes from ½ to 20 inches, except that all valves larger than 4 inches must be fitted with by-pass valves, as described below. The size of the diaphragm does not change with each size of the valve, there being only two sizes used, one for valves from ½ to 1½ inches, and the other for valves 2 inches and larger. This is made possible because the movement of the diaphragm affects only a smaller controlling valve J, and not the main valve D directly.

Steam enters at R under boiler pressure and leaves at T under the reduced pressure. The figure shows the main valve closed, as it is when no steam is on R. Main valve D is held against its seat by the spring E. Attached to the upper end of its stem is the piston F which works in a cylinder, the lower end of which is always in communication with the outlet T, and the upper end of which is put in communication with R, when the controlling valve J opens. This valve is held against its seat by the small spring K, and its stem is independent of the small diaphragm G. The under side of G is always in communication with outlet T, and its upper side subject to the tension of the adjusting spring L acting on the block or seat N.

When the valve is to be regulated after being secured in place, the cap O is unscrewed until there is no tension on spring L. The drain cocks on the delivery side and at the bottom of the lower bonnet C (not shown) must be opened, and then the by-pass valves, if fitted, opened, or the stop valve on the inlet side opened very slowly until it is opened full. The cap O is now screwed down slowly, a little at a time, to allow the regulator to become thoroughly heated and drained. When the desired pressure on the delivery side has been obtained (the drains being closed when all water has been blown out and the delivery pressure is steady), the lock nut P is set up tight against O, and the two locked together.

When the cap O is screwed down, it puts L under tension. The latter forces G down, and partially opens valve J against the spring K and the inlet steam pressure, which has been admitted to the back of J through the port S. The steam reaches the top of F through the port V and forces the piston and the main

valve D down and partially open. Steam is now wire-drawn from R into T and, at the reduced pressure, acts on the bottom of diaphragm G, through the port U, against the tension of the spring L, and acts also on the under side of the piston F, through a number of holes in the bottom of the cylinder. So long as the pressure in T, and, therefore, that under the diaphragm, balances the tension of the spring L, there will be no change in the position of J as fixed by the setting of spring L, and, hence, no change in F and D. But, if the delivery pressure falls, spring L acts downwards and opens J wider, which results in a greater pressure on top of F and a correspondingly greater opening of D, and, therefore, in a greater pressure in T, until equilibrium is again restored between the two sides of the diaphragm. The action is similar, only in a reversed manner, when the pressure in T rises.

The diaphragm is made of a non-corrosive spring metal, like phosphor bronze; all springs are heavily nickel-plated, and the valve chamber A, bonnets, valves, and other parts are of composition. Piston F is fitted with two small packing rings, which prevent steam from blowing through from the upper to the lower side. These rings are not solid circles, but are cut through in one place, at an angle, the opening between the ends, when the outside surface of the rings bear against the walls of the cylinder all around, being a scant $\frac{1}{32}$ inch. The elasticity of the rings is sufficient to permit them to be slipped over the piston and into the grooves, and then to press out against the cylinder, without interfering with the movement of the piston. Such rings are called *snap rings*.

The gaskets, which make the steam-tight joints at 1, 2, 3, and 4, are of soft, thin sheet copper, and care must be used in fitting them, especially 1 and 2, so that ports U and S will not be obstructed. When it is necessary to grind in or reseat valve J, the stem must be shortened a little, so that the original distance between the top of valve stem and diaphragm may be maintained. Main valve D should be ground in, when necessary, with piston F in place to serve as a guide. When it becomes necessary to unscrew casing Z, in order to examine or renew the diaphragm, care must be used, after assembling the parts, that Z is screwed down steam-tight on the diaphragm. If this has not been done,

it will be shown by the escape of steam or water from the tell-tale hole at W. If this leak is not stopped, the regulator will soon be out of working order.

It has been found absolutely necessary, in order to prevent pounding or other injury, to fit all regulators above 4 inches with by-pass valves, so that the pressure on the delivery side can be raised before the stop valve on the inlet pipe is opened fully. With some of the older regulators, these by-passes may not have been fitted, in which case the omission should be supplied, and the by-passes used according to the following instructions:

Whenever possible, the steam pipe on the inlet side of the stop valve should be connected to the delivery pipe on the delivery side of regulator; in this way, the stop valve on the inlet side need not be touched until steam has been raised to the desired pressure on the delivery side of regulator, after which it should be opened fully. When this arrangement is not possible, the by-pass may connect the regulator side of the stop valve with the discharge side of the regulator, the connections being made on their respective pipes. When neither way is practicable, the by-pass may connect the inlet and discharge sides of the regulator casting directly.

When steam is to be turned on, the by-pass must always be opened first. Where the by-pass is connected to the outlet side of the stop valve, as in the last two cases mentioned, this valve should be opened just sufficiently to feed the by-pass fast enough to heat the pipes and raise the pressure on the delivery side of the regulator to that required; when this has been done, the stop valve is opened fully and the by-pass closed.

Steam Signalling Apparatus.—This consists of an ordinary whistle on all vessels, to which a siren or a shrieking whistle is generally added, both being connected to the auxiliary steam pipe system. The whistle is secured close to the forward side of the forward smoke pipe, well above the level of the awnings. The shrieking whistle and siren are similarly placed, but the latter is frequently secured away from the smoke pipe, in order to give a greater compass to the trumpet mouth. The branch pipes leading to the whistles and siren have a stop valve at their lower, and a working valve at their upper ends, and all are fitted with drains and traps at their lowest points, so that the pipes may be kept

drained at all times. Provision for expansion of the pipes is made between the drains and the auxiliary steam pipe.

Whistles.—The various forms, called *bell, chime,* and *shrieking* whistles, are constructed on the same principle, the sound being produced by steam issuing from a narrow circular orifice and striking the thin edge of a cylindrical bell, which is secured at a certain distance above the orifice. The tone depends chiefly on the steam pressure and the length of the column of air or steam inside of the bell.

Fig. 47 illustrates a three-tone chime whistle made by the American Steam Gage and Valve Manufacturing Company. The bell is shown by the long cylinder, which is adjustable on a vertical central rod by means of a thread, the nut on top securing it in place. In the cup-shaped part, directly below the bell, is the narrow annular orifice, through which steam passes from the operating valve below.

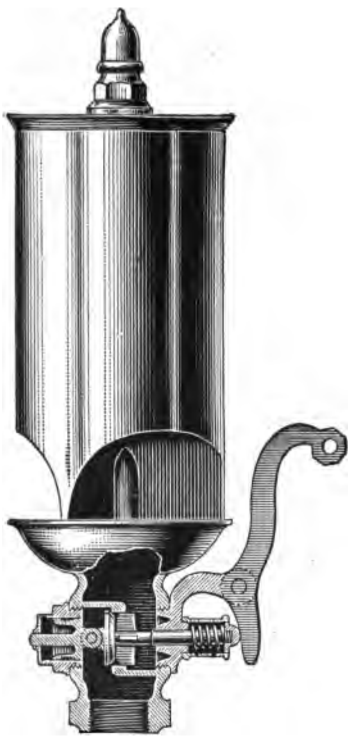


FIG. 47.

FIG. 48.

In the ordinary bell whistle, the lower end of the cylinder is straight, not cut away as in the figure, and its interior is a plain cylinder like that in Fig. 48. When steam blows through the orifice and strikes this plain bell, only one note is produced for a given adjustment and steam pressure. As the latter is not

always constant, the sounds produced by the ordinary whistle are usually discordant and shrill. To overcome this, in a measure, the chime whistle was introduced. It will be seen from Fig. 47 that there are divisions or compartments in the interior of the bell; these, being of different lengths, produce three different notes, which, under proper conditions, harmonize. Four-tone chimes are also made, in which the bell is, of course, divided into four compartments. While the range of pressure under which chimes will be musical and clear is somewhat larger than that of the ordinary whistle, the bell should be raised or lowered with the steam pressure for perfect working. A small reducing valve, fitted in the supply pipe and set for a certain discharge pressure, at which the bell could be permanently adjusted, would obviate all trouble.

Steam is admitted to the cup bottom of the whistle by a valve, which is opened against the steam pressure and a spring by a bell crank lever worked by direct pull from the bridge. With large valves and high pressures, a balanced or compound valve, as in Fig. 47, is necessary for easy working. A small piston is secured to the back of the valve and thus reduces the unbalanced area under pressure.

Shrieking Whistle.—The action of this whistle, Fig. 48, as made by the Lunkenheimer Co., will be easily understood from what has been said above. By means of the movable piston inside of the bell and the connection below, the length of the column of air can be changed at will, and a succession of rising and falling notes produced, which serve most efficiently as a signal for fire, and closing water-tight doors. The adjusting thread and nut are, in this case, below the bell.

Siren.—This is a more powerful instrument than the whistle, and, as the sound made by it can be projected in any direction by means of a trumpet mouth, it is more efficient as a fog signal. Fig. 49 shows a form usual in our service.

Steam is admitted at I by means of a working valve, as in the whistle, and fills the annular chamber O, which is pierced by a number of vertical beveled slits at its upper part. A cup-shaped wheel W, which is pierced by similar slits, but beveled in the opposite direction, as shown in the small sectional view, is fitted inside to revolve freely on the central spindle S. As the steam

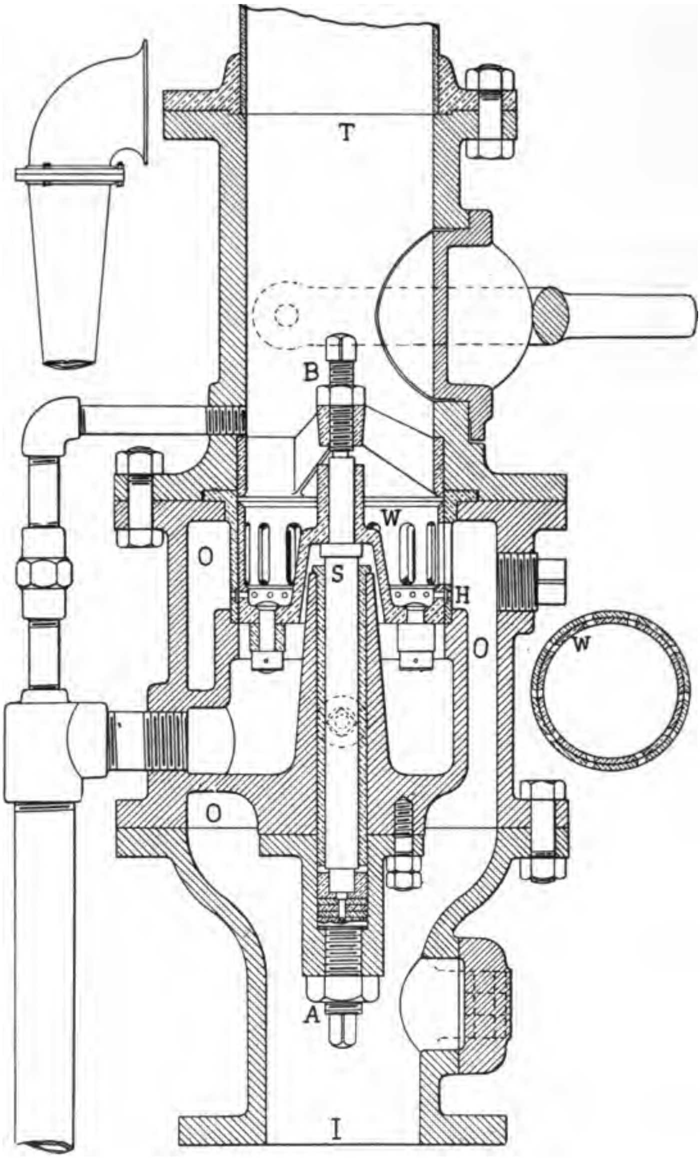


FIG. 49.

from O rushes through the outer slits and against the sides of the slits in the cup, it causes the latter to revolve at a high rate of speed. The alternate closing and opening of the slits set up violent vibrations in the column of air and escaping steam in the trumpet-shaped pipe fitted above T. The pitch of the sound will depend on the speed of the wheel, and no adjustment is necessary for varying steam pressures.

Should the wheel, when it stops revolving, close the outer slits, the siren can still be started by means of the small auxiliary holes H, the spacing of these being different from that of the slits. In another form of siren, the slits are spaced unevenly, and no auxiliary holes are needed. The method of balancing and supporting the cup is shown by the figure. A and B are adjusting bolts for the spindle, access to them being given by removing the handhole plates. The trumpet mouth, shown to a reduced scale, is fitted to turn, either direct by a handle or by means of gearing from below.

CHAPTER XI.

TYPES OF SHELL BOILERS.

Besides the form of shell boiler explained in general terms in the beginning of this book, others are in use. Shell boilers may be divided into two classes, *return tube,* and *direct tube* or *straight-away* boilers. These names, taken from the path of the gases of combustion, distinguish the two classes sufficiently. In the return tube boiler, the gases pass to the back of the furnace, rise and return through the tubes to the front of the boiler and thence into the uptake; in the direct tube, the gases enter the tubes at the back end of the combustion chamber and pass into the uptake beyond. Return tube boilers are further distinguished as *single-* or *double-ended,* the latter being practically two single-ended boilers united back to back, with the back head of each left off. They are still further distinguished by the number of furnaces in each boiler, which ranges from one to four in each end. Direct tube boilers must necessarily be single-ended. They have either two or three furnaces. Another form of shell boiler, which is a direct tube boiler, is the marine locomotive boiler.

Plates I and II show a double-ended, return tube boiler with eight furnaces. Fig. 50 shows a single-ended, four-furnace, return tube boiler. The right half of the figure is a front elevation of the boiler, with the connections and uptake removed, and the left half, a section through the middle of the length of the boiler. B, B are the furnaces, C the combustion chamber, one for each furnace, and D the tubes. The heads, instead of being flat as in the example shown in the plates, are bent back at the top. By this construction, the two upper rows of braces become unnecessary, but the steam space is somewhat reduced. The manner of staying the combustion chamber sides to each other and to the shell is shown by the screw stays O, O. The manner of staying the unsecured parts of the flat back head, between adjoining combustion chambers, is shown by the T girders, which are riveted to the back

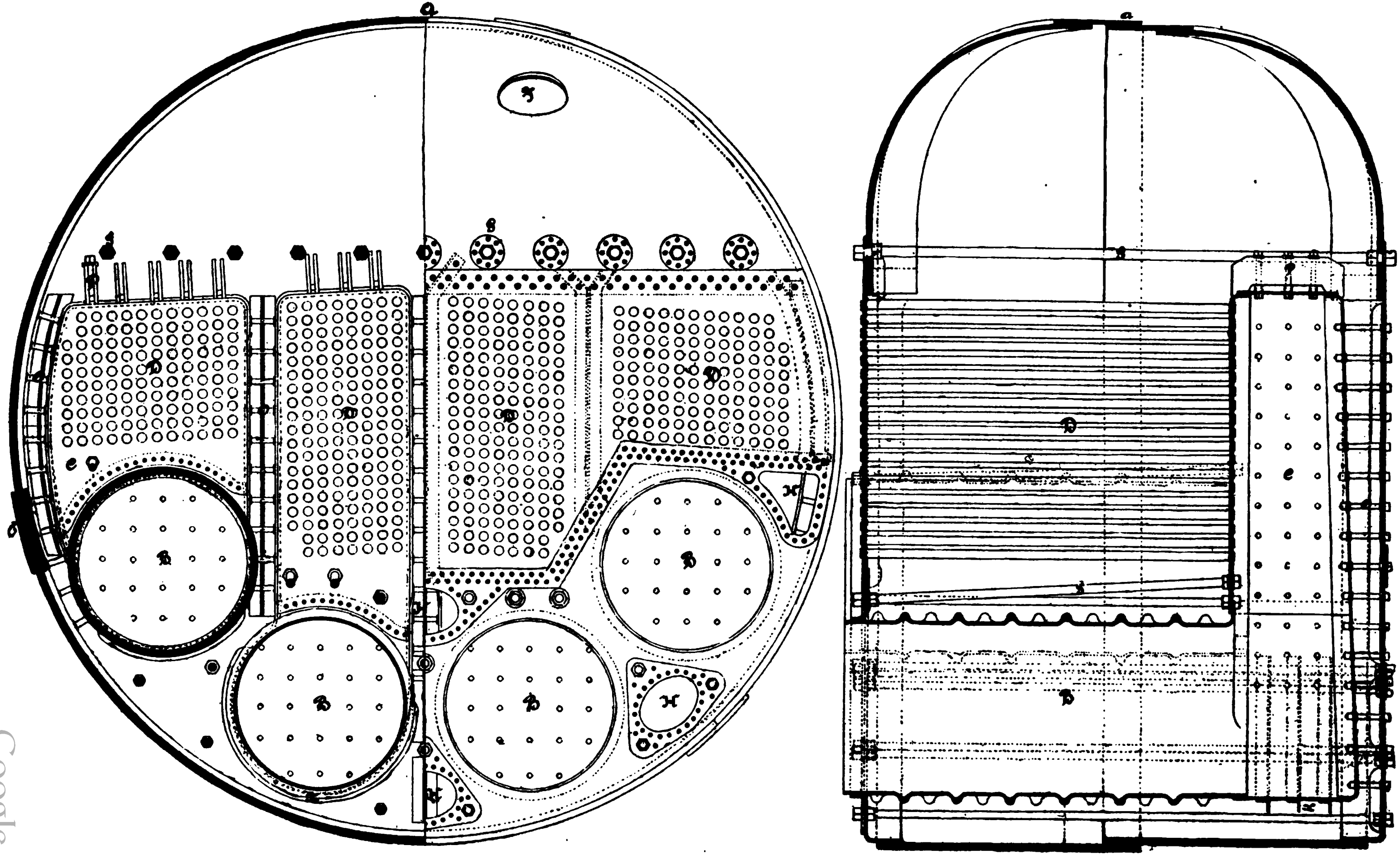


Fig. 50.

head. The front head between adjoining nests of tubes is similarly stayed. The single-ended boiler is heavier and more expensive than the double-ended one for the proportionate heating surface, and its evaporative efficiency is, in practice, generally lower. The type of furnace shown in the side elevation is different from the corrugated one shown in the plates. The remaining parts are similar to those of the double-ended boiler already described.

The direct tube type, Fig. 51, is fitted in ships of light draught and little vertical height, so that the boiler may be brought below the protective deck. They are fitted on the gunboats of the "Yorktown" class and others. The boiler shown is fitted on the "Bancroft" and has two furnaces, each with a separate combustion chamber. In order to be able to get at the back ends of the tubes, for cleaning and overhauling, extra length of fire room must be allowed there. In order to put in the tubes without increasing this space too much, the athwartship bulkhead between the forward and after boiler compartments has removable sections opposite the tubes. By this means, as the boilers on the same fore and aft line are placed back to back, the space back of both boilers can be utilized for either boiler. The connections and uptakes, not shown, are at the back of the boiler. As the top of the furnace is very near the water level (it is, as shown, on a level with the top row of tubes), this boiler evaporates very quickly and more efficiently than the return tube type. The total heating surface for the space occupied is small.

The boilers of the "Yorktown" have each three furnaces with a common combustion chamber, and those of the "Vesuvius," one furnace each. The "Petrel's" boilers have two furnaces each with a common combustion chamber.

The marine locomotive type is, as its name implies, similar to the locomotive boiler on shore. As fitted in the "Castine" and "Machias," and shown in Fig. 52, there are two furnaces with a common combustion chamber. The shell is cylindrical from the combustion chamber to the back end, and is composed of a cylindrical top and flat sides at the front end. The furnace is built chiefly of flat plates, and the top of the combustion chamber is on a line with the top of the furnace. The tubes F lead direct into the back connection and uptake, as in the gunboat boiler.

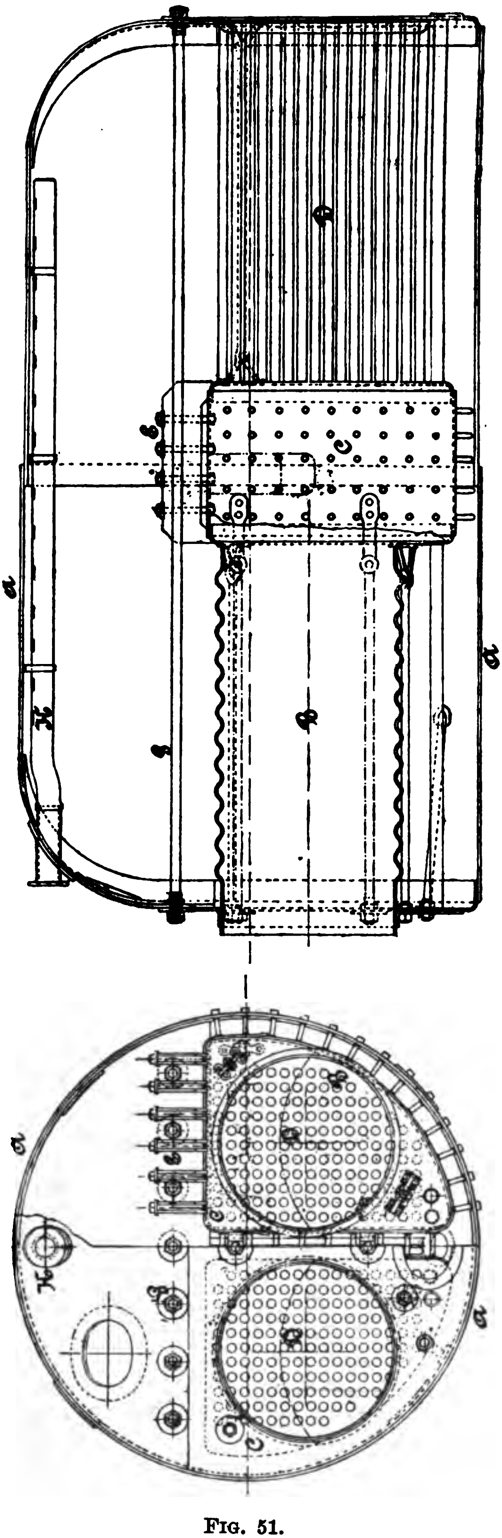


FIG. 51.

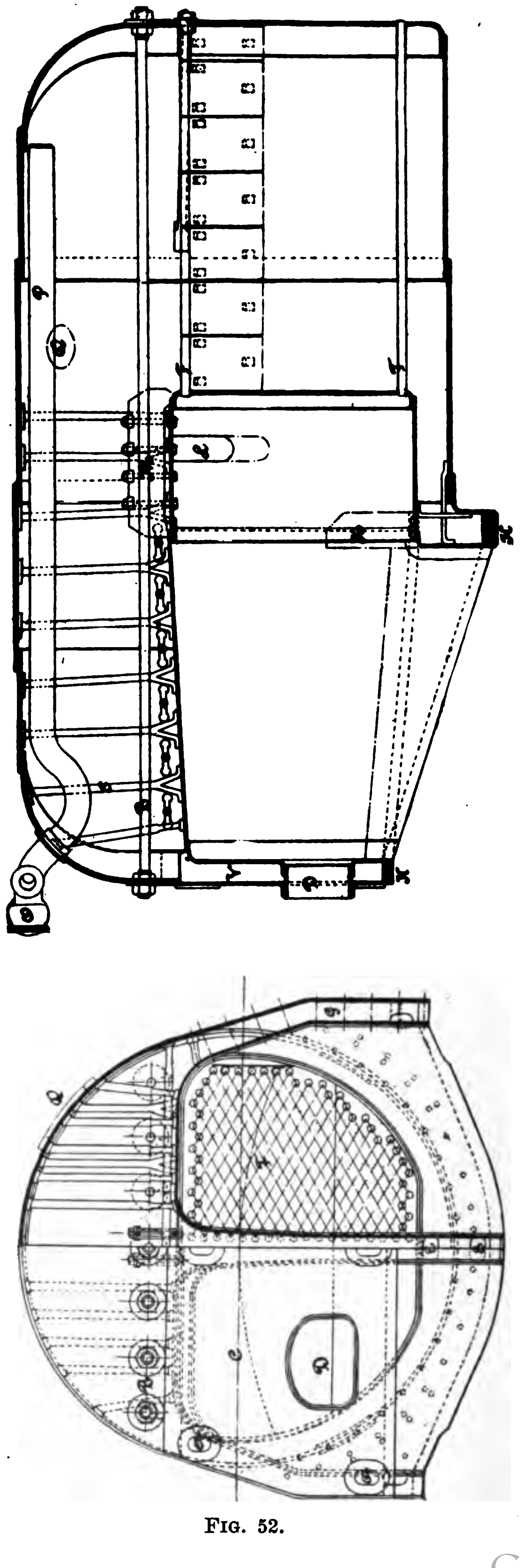


Fig. 52.

The ash pit is not, like in the types shown above, a part of the boiler. As the furnaces are large flat surfaces, they are tied to the top of the boiler by stays S. The sides of the furnaces being also flat, are stayed to each other and to the flat sides of the boiler by screw stays, the space G being called a water leg. The top of the combustion chamber, being flat and larger than usual, is supported by the girders M and by stays riveted to the top of the boiler. To deflect the gases downward, and prevent them from striking the tube ends directly, a *hanging bridge* L is built down from the top of the combustion chamber. The front of the furnace is made by a water leg V similar to G. As will be seen, there is considerable room above the fire to allow for the combustion of the gases. As this type requires much more bracing and staying than the others, it is, therefore, practically inaccessible for cleaning. It is lighter for the heating surface contained than the previous types, and much more heating, as well as grate surface, can be put in the same space allowed for boilers. But, in spite of its advantages, it is not a suitable boiler for marine purposes, where salt water may have to be used, and is not fitted any more.

The class and type of shell boilers chosen for a particular vessel depend on the service required, the draught of the ship, and the space which is allotted to the machinery. In addition, the engines and boilers must be so placed as to be best protected from injury by gun fire. To satisfy this last condition, the whole machinery is installed below the protective deck, and is, therefore, generally very much crowded. Again, it is always desired that the greatest power be put in the given space.

The boiler power depends on the quantity of water evaporated in a given time, and this depends chiefly on the amount and efficiency of the heating surface in the boilers. The variable dimensions of a boiler are its diameter and length, and these are changed to suit the different conditions of space allotted, so that the greatest practical amount of heating surface is obtained. Hence, in large ships, where the draught is great and, therefore, the vertical height of the allotted space is large, the return tube boiler is used, the necessary heating surface being obtained by a large diameter of shell. In ships of light draught, the vertical height will be small, and the necessary heating surface must be

obtained by increasing the length of the boiler, involving the use of a direct tube boiler.

The efficiency or evaporative power of a given boiler depends on the efficiency of combustion and on the efficiency of the heating surface. The former has been explained in Chapters III and IV, and we can now take up the second one and see what effect the various types of boilers have on this efficiency.

The efficiency of the heating surface is the ratio between the quantity of heat transmitted to the water in the boiler to that available for transmission. The ratio of the available heat to the total heat value of the fuel is the *efficiency of combustion.* In order to compare the efficiencies of boilers properly, each of these factors should be taken separately.

The efficiency of the heating surface depends, practically, (1) on the amount of that surface, and its position and arrangement, (2) its cleanliness, (3) the difference of temperature between the heat of the gases and of the water, and the nature of the heated gases, and (4) the time allowed for the transmission of heat.

1. The amount or extent of all heating surfaces of a boiler is taken as the total heating surface, although the value or efficiency, as transmitters of heat, of the different parts is by no means the same. This value decreases rapidly as the distance of the surface from the fire increases. In a shell boiler, the crowns of the furnaces are the most efficient heating surfaces, then come the tops of the combustion chamber, next the sides, and last, the tubes. The furnace crowns and combustion chamber account for about 55 per cent of the total evaporation. In tubulous boilers, the tubes or parts of tubes with which the flames first come in contact are the most efficient, these, in some forms of boilers, accounting for about 60 per cent of the total evaporation. Beyond a certain limit, the addition of more heating surface, which means practically more tube surface, will not increase the power of the boiler.

One of the methods of expressing the extent of the total heating surface is to compare it with the total grate surface of the boiler. The total heating surface in shell boilers varies in our ships from 26 to 35 times that of the total grate surface, being in some few cases higher, and in the case of the "Wilmington," 42. This ratio is usually written as follows: H. S. ÷ G. S. = 35, or

whatever the value may be. In our tubulous boilers, H. S. ÷ G. S. = 37 to 43, as a rule, for large ships, and from 47 to 62 for torpedo boats and destroyers.

Steam will be disengaged much more freely from a flat horizontal surface, heated from below, than from a vertical one, while practically none is disengaged from a flat, or even curved, surface below the fire. If the flat top surface be made concave towards the fire, it will be better adapted for receiving the radiant heat, and also for facilitating the flow of particles of water towards the crown of the curve, from which most of the steam bubbles arise. Any intermediate position of side heating surfaces, between the vertical and horizontal, will improve the disengagement of the steam bubbles.

From the above, we see that the crown of the internal furnaces in shell boilers is most effective, while the sides, along the grate bars, are less so, and the part below the grate bars may be omitted as useful heating surface. Instead of making the backs of combustion chambers vertical, it will be noticed that they are inclined. Often the tops of these chambers are curved, thereby increasing their efficiency slightly. The back tube plate is not inclined, for practical reasons in fitting the tubes. The tubes, similarly to the furnaces, offer really only the upper halves of their surfaces as effective heating surfaces, especially when soot is allowed to collect on the lower halves. Yet, as the whole inner surface of the tube, when clean, is in contact with the flame or heated gases, and the whole outside is surrounded by the hottest water (in return tube boilers), the heating surface of tubes in all boilers is calculated from the outside diameter.

In tubulous boilers, where the fire is on the outside of the tubes, these would be very inefficient as heating surfaces if they were horizontal, as the steam bubbles would then collect on the crown. Hence, these tubes are always inclined, the discharge end, naturally, being the higher. As they are generally more nearly across the path of the gases, instead of parallel to it, their efficiency as heating surface is greater than that of the tubes of shell boilers.

2. That cleanliness of both side of the heating surfaces is necessary to efficiency, is readily understood from what has already been said about the very poor conductivity of scale and especially

grease, deposited on the water side, and soot on the fire side. The heaviest deposits will, naturally, occur where there is least evaporation.

3. While little is known about the exact manner in which heat is transferred through a plate from the heated gases on one side to the water on the other, it is established that the greater the difference in temperature between the gases and the water, other things being equal, the greater will be the transference of heat, or the evaporative power of any part of the heating surface; furthermore, that flame and the incandescent fuel are very much better heating mediums than the hot transparent gases.

Experiments have been made with shell boilers to test the evaporative power of different parts of the tubes, all showing that this decreased for each section of the length away from the combustion chamber, and that, after a certain limit, no increase in evaporative power would result from an increase in the length of the tubes. The limit in our naval practice is a few inches less than eight feet, the usual length being about one foot less than this. Although the farther end of the tube is less efficient than the combustion chamber end, it still adds to the evaporative power, within the limit of length just given. This is evident from an inspection of the temperatures given in Fig. 5, where the final temperature inside the tube is still about 500 degrees above that of the water on the other side, for a steam pressure of 180 pounds per square inch. In horizontal tubes, the first few inches in length are most efficient and about the same as an equal area of furnace heating surface.

When the draft is increased, the temperature of the escaping gases is also increased, but the flame will extend farther along the tube and thus increase the evaporative power of the whole tube, and, therefore, the rapidity of evaporation. It follows from this that longer tubes can be used efficiently in boilers working under strong forced draft at all times, than in those which work under natural or mild forced draft.

4. The evaporative power of any given heating surface depends on the time allowed for the contact of the hot gases. Hence, when using forced draft, during which a high velocity is imparted to the gases and, therefore, less time is allowed for contact, the efficiency will, on this account, be less than with natural

draft for the same tube area and length, although the rapidity of evaporation in increased, on account of the greater quantity of gases passing through the tubes.

This brings us to the consideration of the diameter and relative length of the tubes of shell boilers. As the heating surface for a given length of the tube depends on the diameter, while the area for the escape of gases varies with the square of the diameter, more tube heating surface can be put into the same space by using small instead of large tubes. But, the diameter of the tubes is limited by the fact that flame, under ordinary draft, will not pass through small long tubes, and, therefore, the useful combustion of the gases cannot extend much beyond the combustion chamber. If the combustion has not then been completed, the flame will be extinguished a few inches inside the tube, and the unconsumed gases will pass up, and may burst into flame at the top of the smoke pipe. If we could burn coke or anthracite at all times, and could burn completely their hydrocarbons and carbonic oxide before these reach the tubes, very small tubes could be used. But with coal that burns with a long flame, the diameter of the tubes must be larger, in order that this flame may not be extinguished. As naval vessels must burn many kinds of coal under varying conditions of draft, a mean must be used for the smallest diameter and greatest length of tube for shell boilers. $2\frac{1}{4}$ inches generally, and sometimes $2\frac{1}{2}$ inches, is the outside diameter of tubes used in our Navy, and the length, usually about 6 feet 6 inches, with occasional extreme cases of tubes about 7 feet 8 inches long. Although the heating surface and the diameter and length of tubes are fixed for a given boiler, an intelligent application of the above principles, when burning different kinds of coal, will result in an appreciable economy.

Kind of Furnace Flues.—Although the cylindrical furnace is less efficient than the rectangular one, chiefly on account of the limited space above and below the grate, yet it is the only one used in shell boilers. It is easier to manufacture, it can be and is made with only two joints which need be kept tight, one at each end, and, as it requires no stays, the interior of the boiler, around the furnaces, is accessible for cleaning. These advantages outweigh its one disadvantage.

The older form, still found on a few of our earlier ships, con-

sists of two or three short plain cylinders, riveted to each other by flanges turned on the ends, with a stiffening ring between the flanges. This joint is called an *Adamson ring* and is shown at A in Fig. 53. For pressures, say above 80 pounds, the plain furnace would not be strong enough without making the plates too thick. This led to the adoption of Fox's corrugated furnaces, made in one length, as shown at B. Later forms of this type are shown by the Purves ribbed flue D, and the more recent Morison suspension furnace C, which is a combination of the Fox and Purves.

The Fox furnace is of equal thickness throughout, and has narrow corrugations, spaced about 6 inches between crests or tops,

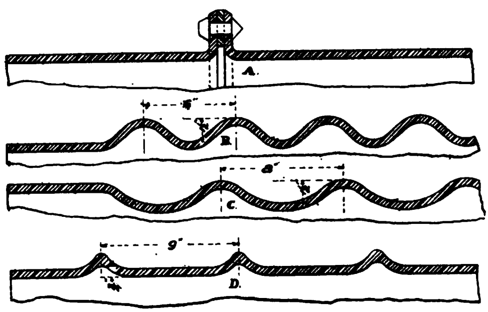


FIG. 53.

and projecting equally above and below the mean diameter of the furnace. The narrow cavity formed on the water side by the inward and downward groove, $1\frac{1}{2}$ inches deep, gives good opportunity for an accumulation of deposits, which is rather difficult to remove properly. As these cavities are nearer the fire, the material, if not clean on the water side, becomes unduly heated and frequently cracks at the bend. This defect is overcome in the Purves furnace, which has the strengthening ribs in the water space, and, therefore, offers no cavities. But the flat surfaces, 9 inches between the ribs, being the weaker are the first to sag or collapse. Owing to the stiffening rib, the thickness of the furnace, and, therefore, its strength, is not the same throughout. In the Morison furnace, the corrugated form is retained for strength, but, by making the outward corrugations shorter and utilizing them as stiffeners, the inward corrugation, *suspended* between them, can be made longer, 8 inches, and, therefore, the small cavities avoided. The thickness of the furnace is uniform.

All furnaces are made of steel, the plate being usually $\frac{9}{16}$ inch thick, with slight variations depending on the quality of the material and the boiler pressure. The least internal diameter varies from about 36 to 42 inches. The corrugations of adjacent furnaces are made to alternate.

Tubes.—These are always straight and are of two kinds, *ordinary* and *stay tubes,* the latter being the heavier or thicker, but both having the same external diameter.

Ordinary Tubes.—These, which are the more numerous in a boiler, are now made from No. 9 to 12 B. W. G. (.148 to .109 inch) thick, with the front ends swelled to a slightly larger external

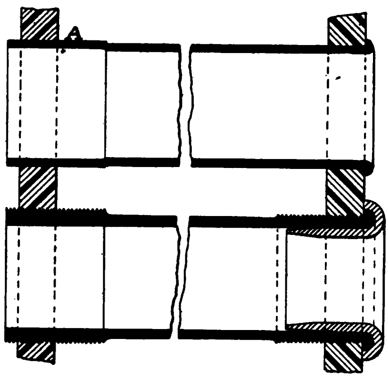


FIG. 54.

diameter, from $\frac{1}{16}$ to $\frac{1}{8}$ inch, to facilitate their entry and removal. The holes in the tube sheets are drilled slightly larger than the tubes, so that the latter can be pushed into place by very slight pressure. Both ends of the tubes are then made tight by an *expander,* the one generally used being Dudgeon's. This consists of a hollow cylindrical frame with usually three steel rollers working in slots. A taper pin passes through the center of the frame and bears against the rollers. A collar is secured to the outside of the frame to prevent the expander from going in too far. When a tube is to be expanded, the frame is pushed in, until the collar, which slips over the outside of the tube, bears against the tube plate. The pin is then driven in slightly and sets out the rollers. This is repeated, the pin being turned after each drive, thus revolving the rollers until the whole circumference of the tubes has been *expanded* against the sides of the hole in the

tube sheet, as shown exaggerated in Fig. 103, VI. The back or combustion chamber end of the tube is then *beaded* over, as in Fig. 54, to protect the end from the fire and to add a little to the holding power. Sometimes, the back tube sheet hole is enlarged or *counterbored* on the fire side, and the tube end beaded into this recess, the remaining space being fitted with a flat ring.

Stay Tubes.—These, as their name shows, act as stays between the two tube sheets and are, therefore, secured in a different manner. They are usually No. 6 B. W. G. (.203 inch) thick, and are re-enforced at both ends to an external diameter, usually $\frac{1}{8}$ inch greater than the rest of the tube, the bore of the tube remaining uniform from end to end. The front ends are then swelled an additional $\frac{1}{8}$ inch, so that the external diameter at this end is $\frac{1}{4}$ inch greater than the body of the tube. Both ends are then threaded, usually parallel, but sometimes taper at the front end. The tube is screwed into the threaded holes in the tube sheets until a tight joint is made in the front sheet. The back end is then expanded and beaded over, and this end and the adjacent sheets are further protected by a cast iron *ferrule,* as shown in Fig. 54. These ferrules, which are sometimes also used in the back ends of the ordinary tubes, have an internal diameter of from $1\frac{1}{2}$ to $1\frac{3}{4}$ inches, and are simply driven into place by slight hammering. The round cap projects over the beaded tube end and, by conducting the heat to a part of the tube surrounded by water, protects the tube end and joint from the direct action of the hot gases. When the caps are burned off, the ferrules can easily be renewed. When cleaning tubes with brushes, these ferrules are liable to be pushed out. Ordinary tubes, when much reduced in thickness by frequent expanding, may be strengthened for a time by straight ferrules expanded in the ends.

The holes in the tube sheets are drilled in vertical and horizontal rows, the spacing between vertical rows being the greater.

This arrangement gives better opportunity for cleaning the tubes on the water side and improves the circulation. While more tubes could be put into a given tube sheet by *staggering* them, i. e., putting them in zigzag, this arrangement interferes entirely with the cleaning and does not improve the circulation.

Tube Stopper.—When a tube leaks, due to a split or to a hole corroded through it while the boiler is under steam, the tube

should be plugged so soon as the discovery is made. This can be done by means of a *tube stopper,* such as is shown in Fig. 55, which can be easily made of materials on board. At least two of these should always be kept on hand.

T is the tube, A being the front, and B, the back tube sheet. The stopper consists of an iron rod R, over which is slipped a pipe P, somewhat shorter than the distance between the tube sheets. There are four washers, two at each end of this pipe, three of which are slightly smaller than the internal diameter, and the fourth one, W, somewhat larger than the outside diameter of the tube. Between these washers, rings of rubber or of any of the softer gasket materials are placed, one or two rings of asbestos

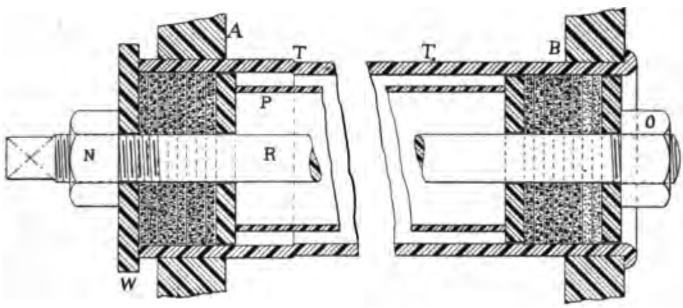


FIG. 55.

finishing the fire end of the stopper. The length of this packing is about one inch. The asbestos rings at the combustion chamber end preserve the rest of the packing from too rapid deterioration. A nut O is fixed at the combustion chamber end of the rod, for convenience, athough any kind of head would do there. The front end of the rod is threaded and fitted with a nut N, which bears against the large washer W. A square head is on this end of the rod.

When a tube is to be plugged, the end O is pushed in until W brings up against the tube. The square head is then held and nut N rapidly set up, until the packing at each end has been sufficiently compressed and enlarged in diameter, to stop the leak. These tube stoppers are very satisfactory, and the packing will last many days before being burned out.

When through steaming, the leaky tube should be replaced by a new one. To get out the old tube, three or four cuts, about two

inches long, are made on the inner circumference of the tube with a cape chisel. Care must be used that the cuts do not go through to the tube sheets and injure them. The parts between the cuts are then beaten in, thus lossening the tube, after which it can be removed by means of a rod run through it. The tube should be pulled out as nearly perpendicular to the tube sheet as possible, to avoid enlarging or injuring the hole. The new tube can then be put in and expanded as already explained.

The leaky tube, before it is thrown away, should be carefully examined; the nature of the leak, whether due to a split, general corrosion, or pitting, the position of the leak, whether on top or bottom, and near the front or back end, and the position of the tube in the boiler should be noted in the steam log. If the leaks are due to some form of corrosion, as is generally the case, a study of these records may reveal and locate the cause.

Clothing and Lagging.—For the purpose of reducing radiation from the large surfaces of shell boilers, they are covered, generally all over, with incombustible, non-conducting material like magnesia, from 1¼ to 1½ inches thick. This *clothing* is put on after the boilers have been put in the ship, tested and painted. In some cases, the clothing on the sides and back head extends down to the saddles only, the rest being left uncovered. Only the top part of the front head is clothed.

This clothing is *lagged* or covered, for protection, by thin, galvanized, wrought iron plates, bolted together through external flanges and held away from the boiler by suitable distance pieces. The clothing and lagging for the bottom of the boiler are made in sections, so as to be easily removable; the clothing is held up against the shell by galvanized iron bands, and the lagging is secured to the boiler by angle irons, held in place by bolts which are tapped part way into the shell plates.

CHAPTER XII.

SHELL BOILERS.

DETAILS OF CONSTRUCTION.

Materials.—The only material which is now permitted to be used for all *boiler plates,* such as those for the shell, heads, tube sheets, combustion chambers and furnace flues, is open-hearth steel, which must not contain more than .04 of 1 per cent of phosphorous and not more than .03 of 1 per cent of sulphur. The material for braces and stays is the same as that for plates; bolts, studs and rivets are generally of the same material, although open-hearth nickel steel may be used. Tubes for shell boilers are of low carbon, mild steel, either seamless, cold-drawn, or lap-welded, or of charcoal iron, lap-welded. Brass tubes were formerly used, the last ones being in the boilers of the "Boston." Such parts as are not essential to the structural strength of the boiler, as uptakes, smoke pipes, casings, furnace doors and air ducts, are of steel, made by either the open-hearth or Bessemer process.

General Features of Construction.—The outer envelope or tank of the boiler, consisting of the shell and heads, is built up of plates riveted together. The plates used for the shell are generally as wide as it is possible to make them, in order to reduce the number of courses or rings necessary to make the required length. The number of plates in a course depends, generally, on the diameter of the boiler. Single-ended return tube boilers, which are rarely longer than 11 feet, are made of one course, each course consisting of from two to four plates. Double-ended boilers, which rarely exceed 21 feet in length, are made of three courses, with three plates in each course. Each head is usually made of three plates of different thicknesses.

The combustion chambers are boxes built up of several flat and curved plates, to the front of which the furnaces are riveted. This structure, the combustion chamber and its furnaces, is secured inside of the shell and heads by the front ends of the furnaces, which are riveted to the lower part of the front head, and by screw stays at the combustion chamber end.

Boilers of "Kearsarge."—We will now explain the details of construction, by taking one of the shorter double-ended boilers of the "Kearsarge" as an example, see Plates VII and VIII, showin, as we proceed, the principal variations which occur in different designs.

The boilers for the "Kearsarge," which are the same as those for the "Kentucky," were built by the Newport News Shipbuilding and Dry Dock Company. There are three double-ended and two single-ended boilers, all 15 feet 8 inches in outside diameter, and constructed for a working pressure of 180 pounds per square inch. Two of the double-ended boilers are 19 feet $9\frac{1}{4}$ inches long, and the other is 20 feet $10\frac{1}{4}$ inches long. The arrangement in the ship is shown in Fig. 35. The total heating surface of all boilers is 22,104 square feet, and the grate surface, 685 square feet.

The heating surface of the boiler, which is taken as an example, is 5320, and the grate surface, equally distributed among eight furnaces, 171.2 square feet; its weight is 96.88 tons without water, and 138.39 tons with water. This weight includes everything necessary for the completed boiler as fitted in the ship, except uptakes and smoke pipe.

Ordering Boiler Plates.—The design of boiler having been approved by the Bureau of Steam Engineering, the contractor has the necessary working drawings or blue prints made for the boiler shop, and orders the material from the steel manufacturers. In ordering boiler plates, the contractor must make an allowance in their size, so that the plates he receives shall be greater than the finished dimensions by, at least, *once* the thickness of the plate along *each end,* and *one-half* of the thickness along *each side.* Take for instance, the lower plate of the middle course, the finished length of which in the boiler is 231 inches, and the finished width, $81\frac{3}{8}$ inches. The size of this plate, as received by the contractor, would be $231 + 2 \times 1\frac{7}{16} = 233\frac{7}{8}$ inches by $81\frac{3}{8} \times 1\frac{7}{16} = 82\frac{13}{16}$ inches.

In rolling the plates at the mills, the edges are irregular and rough, and the sides are, generally, slightly thinner than the central parts of the plate, owing to the spring of long rolls. In order to get a sound and trimmed plate, and enough material for the various test pieces, the edges of the plate, as it comes from the rolls, are cut off in a shearing machine. But, in *shearing* the plate, the material is strained or distressed for some distance

from the edge of the cut. To make sure that this distressed material will be removed only by *planing,* which does not strain the plate, the sheared edges must not be closer to the finished sizes than the limits given above.

Shop Inspection of Plates and Other Material.—When the material is received at the boiler shop of the contractors, it is again examined for surface and other defects which may have escaped the inspector at the steel works. Later, when the material is worked and defects are developed, it may be rejected, although it has successfully passed the inspections. Each plate is also weighed, measured, and gauged for thickness to see that it is fit. All boiler plates that are not to be flanged, stays and tubes, which are satisfactory, are next taken to the pickling tanks.

Pickling.—The object of this operation is the removal of the black mill scale, which, as was shown in Chapter VIII, would become an important factor in the corrosion by galvanic action if it were not removed before finishing the boiler. Besides this reason for its removal, there is the constructive one that riveted joints cannot be made as tight as when the surfaces are metal to metal. It could be removed by the exposure of the plate or other material to the atmosphere for a sufficient length of time, during which it would gradually change to common rust, which could be brushed off easily. This process is naturally slow, and the quicker one of pickling is adopted usually and required for naval work.

The pickling tank is built of wood, and big enough to take the largest plates on *edge,* so that they will be completely immersed in the pickling bath, which is usually a 5 or 6 per cent solution of muriatic acid (HCl) in fresh water. The plates, as many as the tank will hold, are left in this bath about six hours; they are then taken out and the softened scale brushed off with stout brooms or revolving wire brushes, a strong stream of water playing on them during the cleaning. The plates are then immersed in another tank containing a mild solution of quick lime in water, in order to neutralize any acid that may remain on the plates. After leaving this alkaline bath, the plates are washed with fresh water and then stacked to dry. After the above treatment, the plates show a bright, silvery appearance for a short time, during which any surface defects are plainly visible. The common rust which is then formed on these surfaces has no bad effect on the plates, unless they are exposed too long. As the boiler plates are

heavy, they are handled by means of cranes and overhead rails and trolleys.

Laying Out Plates.—The boilermaker is supplied with working drawings or blue prints, as in Plates VII and VIII, or with detailed drawings, showing the finished size and shape of each plate that is to be used in the construction of the boiler. With these guides, he *lays out* on or transfers to each plate the required dimensions and shape in full size, developing on a plane surface such plates as are shown curved in the drawings. Wherever the laying-out operation can be done more quickly and accurately, *templates* of wood or thin sheet iron are first made from the drawings and then used as copies on the plate itself. All straight lines are drawn with a soapstone pencil on the plate, and all arcs are

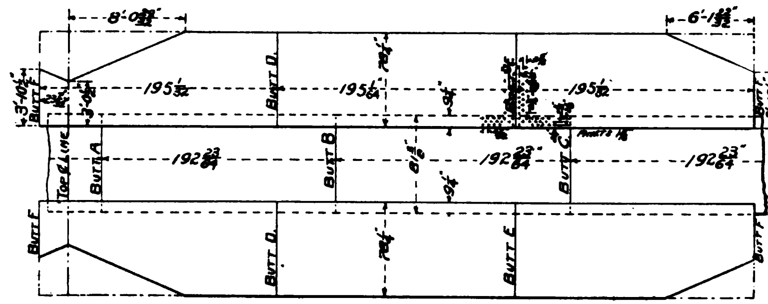


FIG. 56.

scribed with the point of the beam compass and then traced with the soapstone pencil. When all lines have been laid down, they are marked with a center punch. As a help in laying out the plates, a number of distance sticks or battens, which are called *regulators,* are prepared. On these, all of the important distances from the center of the boiler which are likely to be used frequently, such as centers of furnaces, edges of plates, outside of flanges, etc., are marked.

The principal plates of the boiler shown in Plates VII and VIII are laid out as follows.

Laying Out Shell Plates.—The shell is composed of three courses of three plates each, the courses being secured to each other by *treble-riveted lap joints,* and the plates of each course by *treble-riveted double-butt joints.* The joints or seams of the courses and of the courses and heads, which go around the boiler, are called *circum-*

ferential joints, and those of the separate plates, which go along the boiler, are called *longitudinal joints.* The longitudinal seams of adjoining courses *break joint,* that is, they must not be in the same position on the circumference of the boiler.

It will be noticed that the middle course is inside of the two end courses, and that, therefore, its external diameter is less by $2 \times 1\frac{7}{16}$ inches. As only the top ends of the boiler are curved back, the plates forming that part of the shell are the only ones that are not complete rectangles.

The middle course is now developed from the drawing, and laid down on a board to any scale, as shown in Fig. 56. The outside

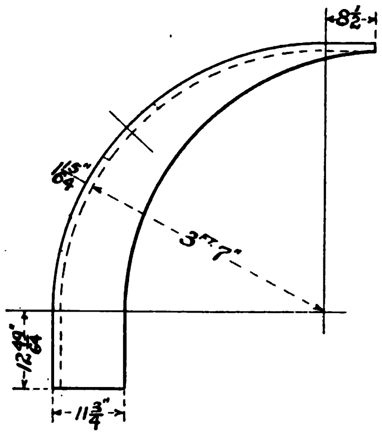


FIG. 57.

diameter of this course is 15 feet 8 inches — $2 \times 1\frac{7}{16}$ inches = 15 feet $5\frac{1}{8}$ inches = also the mean diameter of the boiler. The circumference of the center of the thickness of this course is π (15 feet $5\frac{1}{8}$ inches — $1\frac{7}{16}$ inches) = $577\frac{5}{64}$ inches scant. The butts at the longitudinal joints are shown at A, B and C. The angle between the butts is found by means of a protractor, and from this, the length of each of the three plates. As the angle in this case is 120°, the length is the same for each plate. The total circumference of $577\frac{5}{64}$ inches is, therefore, divided into lengths of $192\frac{23}{64}$ inches. Similarly, the lengths of the plates for the two end courses are found. For convenience in riveting and laying out, the butts D, E, F of the plates of these courses are placed in the same position. As these courses are outside of the middle one, their mean diameter will be 15 feet $5\frac{1}{8}$ inches + $1\frac{7}{16}$ inches = 15 feet $6\frac{9}{16}$ inches.

The nine rectangles can now be drawn in their proper places, with adjoining butts breaking joint, as shown in Fig. 56. We have next to find the proper shape to be cut out of the two top plates, to which the curved heads are to be riveted. The method of finding the curve is similar to that for the top head plate, but the operation will be understood better by laying out the head instead of the shell plate.

Laying Out Top Head Plate.—This plate is $1\frac{15}{64}$ inch thick, and begins to curve back towards the middle of the boiler, at a

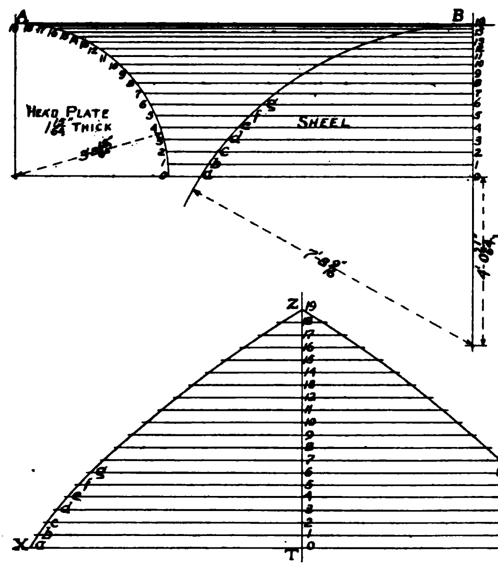


FIG. 58.

height of $12\frac{41}{64}$ inches from the bottom edge, Fig. 57, the curve of the inner surface being the quadrant of a circle of 3 feet 7 inches radius. From the upper end of the quadrant, the plate extends $8\frac{1}{2}$ inches in the direction of the longitudinal axis of the boiler, this straight part being lapped under the outer shell plate. The curved part is developed in the plane of the head of the boiler, and an iron template made of the developed form, as follows:

The quadrant of a circle is laid out, full size, on a board, as at A, Fig. 58, with a radius of 3 feet $8\frac{15}{64}$ inches, or, 3 feet 7 inches plus the thickness of the head plate. To the right of this,

lay out the arc of a circle of 7 feet $8\frac{9}{16}$ inches radius, as at B, the upper end of this arc and of the quadrant being tangent to the same horizontal line, since these arcs correspond to the two sections of the boiler. Divide the quadrant into a number of equal parts, 19 in this case, a spacing of about 3 inches being close enough usually. Square these points over to the center line of the large arc. The lines will intersect the arc in the points a, b, c, and d, and the center line in the points 0, 1, 2, 3, etc.

Now draw the line XY, Fig. 58, on the template iron and erect the perpendicular TZ near its center. On TZ, lay off the *developed* length of the quadrant, or 0-19, using as a radius, 3 feet 7 inches + $\frac{1}{2}$ ($1\frac{15}{64}$ inches). Divide this distance into the same

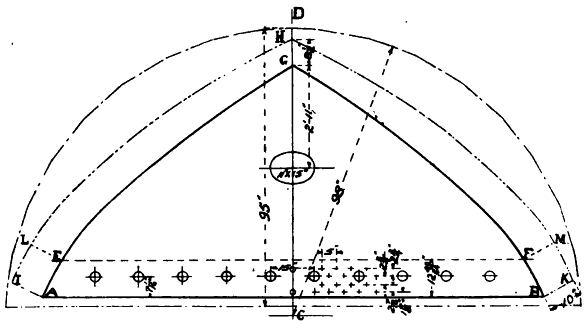


FIG. 59.

number of parts, 19, as was done for the quadrant, and through these points draw lines parallel to XY. It is evident that the width of the head plate at any point 1, 2, 3, must be equal to the chord of the arc of the shell plate at the same corresponding point. Therefore, with the beam compasses set to the length 0a (half of the chord of the arc), mark on XY, on either side of 0, the points *a* and *a*. Similarly the points b, b, etc., are found, and then smooth curves drawn through them by means of a flexible batten. The figure a-19-a is then cut out, and we have the template for the curved part of the head plates. Sometimes, only half of the template is laid out and used.

The curves in the shell plates are found in the same manner, except that the arc for the large circle is divided into equal parts and the points projected over to the quadrant, Fig. 58. The developed length of the arc of the shell plate is then laid down

on the template, and the distances for the points of the curve found from the corresponding chords of the quadrant. The curves, in this case, will consist of straight lines, as shown in Fig. 56.

In Fig. 59, the single-dotted line shows the top head plate as received from the steel mills. First, the line AB is drawn parallel to the straight edge of the plate and at the proper planing distance from it, and then, $12\frac{49}{64}$ inches above it, the line EF, which shows where the plate begins to curve. The center line CD is now drawn and the center of the boiler, which is 4 feet $\frac{21}{64}$ inches below AB, or the lower edge of the finished plate, is determined. The curves AE and BF are then drawn with a radius of 7 feet $8\frac{9}{16}$ inches. The template is now laid down on the plate with the line aa on EF, the point 19 falling at G on CD. The flange line, as shown by the solid line, is then traced on the plate around the curved edges of the template.

Fig. 57 shows the depth of the flange at the bottom of the plate to be $11\frac{3}{4}$ inches for a distance of $12\frac{49}{64}$ inches, and the lap at the top to be $8\frac{1}{2}$ inches, the thickness of the plate being $1\frac{15}{64}$ inches. When plates as thick as this are flanged over at right angles, there is considerable *draw*, or stretching, of the metal, varying from $1\frac{1}{2}$ to $2\frac{1}{2}$ inches. In laying out the line of the *edge* of the flange, the boilermaker must make an allowance for this draw. Therefore, the distances AI, EL, FM and BK are laid out normal to the curves at A, E, F and B, 10 inches instead of $11\frac{3}{4}$ inches. As the lap at the top is nearly straight, no allowance for draw is made, and GH is laid out $8\frac{1}{2}$ inches long. Then a number of distances are laid out normal to the flange lines AG and BG, tapering regularly from 10 to $8\frac{1}{2}$ inches in length, and fair curves, IH and KH, drawn through these points. The arcs IL and KM are drawn with a radius of 7 feet $8\frac{9}{16}$ inches $+$ 10 inches $=$ 8 feet $6\frac{9}{16}$ inches.

The line of stay holes is now drawn on the plate, its distance from the edge, $7\frac{1}{16}$ inches, being obtained from Plate VII. The pitch of the holes, 15 inches, which has been worked on a regulator, is then transferred to the plate. The lines and the spacing of the rivet holes are laid out in similar manner.

The curved head plate just described is used in all of our modern double-ended boilers. It is stronger than a flat plate and needs no bracing in the curved part. The steam room of the

boiler is, therefore, nearly clear of braces. For single-ended boilers, this sheet is frequently made flat, the flanges being turned either in or out, as shown in Fig. 60. The laying out of the sheet is then very simple. Extra lines of stay holes for the flat part must be laid out. Where the flange is turned in, the boiler can be made shorter, for the same steam space, than when it is turned out. The riveting of the plate to the shell is more easily done in the latter case. For large boilers, the flange is generally turned in.

Laying Out Furnace Plate.—This is the lower plate of each head of the double-ended boiler, Plates VII and VIII. In a single-ended boiler, the lower plate of the back head is flat and flanged around the curved part to meet the shell, as in Fig. 50.

The furnace plate, $\frac{3}{4}$ inch thick, is received from the mills as a segment of a circle, as shown by the single-dotted line in Fig. 61. There are to be made four holes for the furnace flues, which

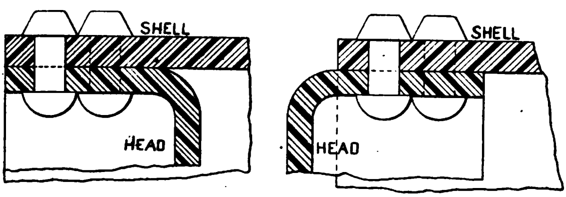


FIG. 60.

are always flanged *outwardly*, a flange around the arc, which is always turned *inwardly*, and five manholes of the shapes shown, which are to be flanged inwardly. The straight or upper edge is to be shaped as shown, and is to have two lines of rivet holes. Holes for braces are to be laid out.

The base line AB is first laid out parallel to the straight edge of the plate, and CD drawn perpendicular to it at its middle point. As the plate is not deep enough to contain the center of the boiler, a board is put under it, and on this is drawn an extension of DC. The distance of the center of the boiler from AB is found from Plate VII and marked on the board. The arcs of the circumferential flange line and of the edge of this flange are now laid out, the radii, 7 feet $8\frac{9}{16}$ inches and 8 feet 6 inches, being obtained from the regulator, as previously explained. The compass is next set at 5 feet $5\frac{3}{4}$ inches, which is the radius of the circle of furnace centers, and the arc EFG struck. By referring to Plate VII, we see that the centers of the furnaces are 3 feet 9 inches apart,

and, as they are symmetrical to the center line CD, the center lines of the two lower furnaces are 1 foot 10½ inches from CD. The four centers are, therefore, readily laid out.

The circles for the flange line of the furnace opening, 3 feet 4⅛ inches in diameter, and for the flange edge, 3 feet 4⅛ inches — 2 x 4 inches = 2 feet 8⅛ inches in diameter, are now struck. The major axis of each elliptical manhole is parallel to the chord of the arc connecting the centers of the two adjacent furnaces, and is 21 inches from this chord in the case of the three lower holes, and 20¼ inches in the case of the middle hole. The flanges of all manholes are 2 inches deep, therefore, the elliptical holes are

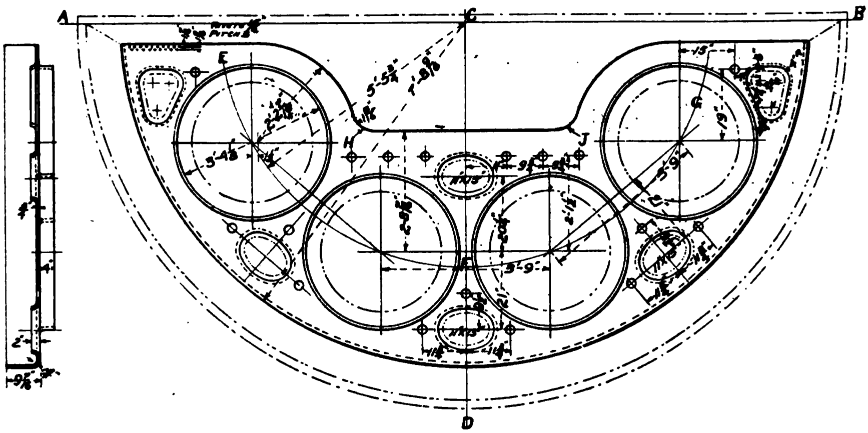


FIG. 61.

laid out 11 by 15 inches for the flange line, and 9 by 13 inches for the flange edge. The irregularly-shaped wing manholes are laid out from the distances and radii given for the flange line, and then the flange edge, 2 inches inside of that. The centers of the stay-holes are readily laid out from the distances given in the working drawings.

The upper edge of the plate, or what is the straight edge of the plate as received, is now laid out. The line HJ is drawn parallel to the line connecting the centers of the two lower furnaces, and 2 feet 4 inches + $4\frac{7}{16}$ inches = 2 feet $8\frac{7}{16}$ inches from it. The increase of $4\frac{7}{16}$ inches is for the lap of the furnace and tube plates. The curved parts around the inner side of the wing furnaces are struck with a radius of 22 inches + $4\frac{7}{16}$ inches = 2 feet $2\frac{7}{16}$ inches, the centers being on the horizontal center line of the wing furnaces,

and $1\frac{1}{2}$ inches nearer to the center line CD. The straight parts above the wing furnaces are parallel to the edge line AB and tangent to the curves just drawn. The small connecting arcs are then laid out with the radius $6\frac{1}{4}$ inches — $4\frac{7}{16}$ inches $= 1\frac{13}{16}$ inches. The laying out of the plate is completed by marking the centers of the rivet holes, as spaced in Plates VII and VIII.

Tube Sheet.—This is the middle plate of the head and is shown in Fig. 62, the same notation of lines being used as in the previous figures.

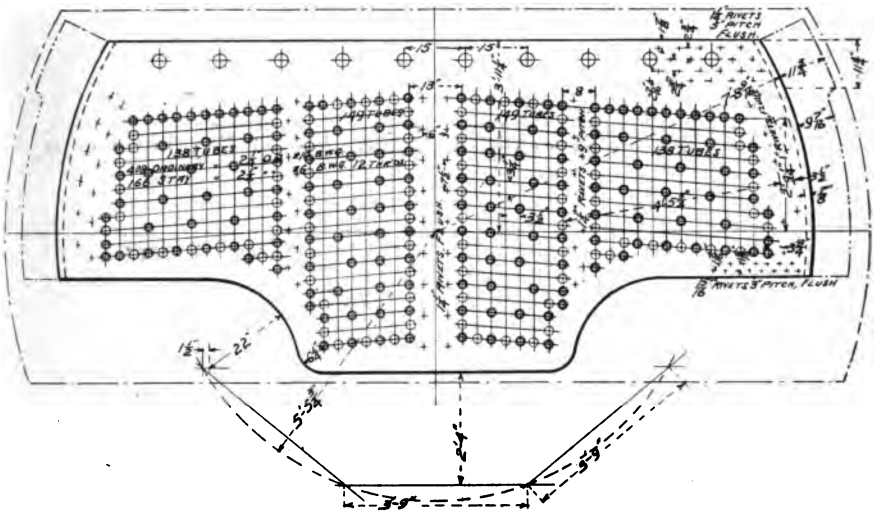


FIG. 62.

This plate is flanged only at the sides where it enters the shell. The top is straight and the bottom shaped to conform to the top of the furnace plate. It will be noticed that the top of this plate laps over the top head plate, and its bottom is overlapped by the top of the furnace plate. The laying-out of the holes for the stays, rivets and tubes will be understood from the preceding explanations, all necessary dimensions and directions being obtained from the working drawings. The holes for the tubes are not laid out until the tube sheet has been flanged.

The laying-out of the remainder of the boiler plates can now be understood without further description. As all corrugated and ribbed furnaces are made by special manufacturers, the con-

tractors for the machinery order them with the back ends flanged, and with the necessary lap, as required by the boiler drawings.

Shell plates, and all flat plates which are not to be flanged, are next put in the planing machines, where their edges are planed down to the finished sizes as given by the center punch marks. The edges which are to be calked are beveled in the planer, the angle being about 7° for plates $\frac{3}{4}$ inch thick and over, and about 15° for lighter plates. The butts of shell plates may also have to be beveled slightly, in order to make them meet squarely after these plates are curved to the proper diameter. The butt straps are planed and beveled, and are then curved to shape in the flanging press.

Drilling Plates.—No punching of rivet or other holes is permitted in plates which are essential to the structural strength of the boiler, as this operation distresses the material very much and tends to irregularity in the spacing of the holes. The latter results in bad workmanship, as the men will use a drift to try to bring the unfair holes in the two plates together, and then use a rivet smaller than the designed size.

The machinery specifications for our ships require that all rivet holes in shell plates shall be drilled *in place after bending* the plates. Variations from this excellent practice have sometimes been allowed for sufficient reasons. For instance, the rivet holes for the circumferential joints of the outside courses of a double-ended boiler, like the "Kearsarge's," and the holes in the middle course for the screw stays of the combustion chambers, were drilled *before* bending the plates, and *tack holes* (small holes for temporary bolts) in the middle course were drilled *after* bending. All of these holes were drilled $\frac{1}{8}$ inch smaller in diameter than the finished hole and later reamed out to finished size.

The separate flat plates composing the shell are taken to a flanging machine, where their ends, for a length of from ten to fifteen inches, are bent cold to the exact curve of the shell, and then to the large "three-roll" machine, where the rest of the plate is bent cold to the proper circle. This special setting of the ends of the plates is necessary, because it is impossible to properly curve them in any bending rolls. The reason will be understood by an inspection of the position of the rolls of the usual three-roll machine. The smaller the diameter of the rolls, the shorter will be the unbent ends. Butt straps, after planing to size and shape, are usually curved in a hydraulic press.

Tack holes, $\frac{1}{8}$ inch smaller in diameter than the finished rivet hole, are now drilled, at intervals, in all shell plates and their butt straps. The three sheets of each course are butted and bolted together, with butt straps in place, by bolts passing through the tack holes. The butt straps of the two outer courses need no fitting other than planing to size, but the outside straps for the middle course must be fitted under the edges of the outer courses. The usual and best method is shown in Fig. 63, in which, for convenience and clearness, the joint A, Plate VII, has been shifted to the top of the boiler, and the longitudinal section taken through the butt of the middle course plates. The inner butt strap B′ is rectangular, like the rest of the butt straps, and needs no special fitting at the ends. The outer butt strap B is planed down on each side to form a lip which passes under the outer courses. The latter are chipped and filed, or planed before bending, on

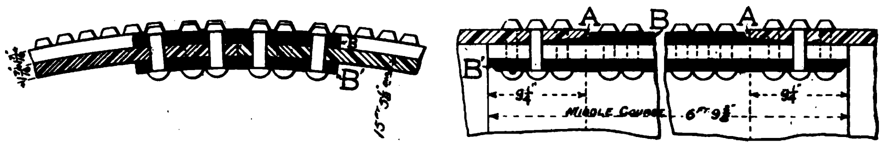


FIG. 63.

the inside to suit the lips of the butt and make smooth joints. Enough clearance is left at A, A, for calking.

The three courses are now lapped and bolted together, care being taken that the lap of the outer courses over the middle one is exactly $9\frac{1}{4}$ inches. The whole shell is then taken to the drilling machine, and the holes for the rivets drilled according to the spacing previously marked on the outer plates and butt straps. If the variation in the specifications, mentioned above, has been allowed, the holes already drilled in the outer courses serve as guides for drilling those in the middle course. The holes for the screw stays of combustion chamber are drilled at this time. The tack holes are also reamed out to finished size, the plates being bolted together through some of the finished holes. Any unfairness in the tack holes is thus made to disappear, without using the dangerous means of the drift pin or a smaller rivet.

Hydraulic riveting is required wherever it can be used; where the riveting must be done by hand, the holes must be coned and conical rivets used. All of the joints in the shell can be made by

machine-riveting, and the holes are, therefore, drilled as shown on the left in Fig. 64; those for hand riveting are shown on the right. All holes are drilled $\frac{1}{16}$ inch larger than the rivet. With machine-riveting, the end of the rivet is formed either into a button head (dotted lines), or into a truncated cone. With hand riveting, the conical head is generally formed.

The drilled plates of the shell are next taken apart, the burr, left by the drill, removed, and the holes cleaned, so that the plates may come metal to metal. The courses are then reassembled, being held together by bolts at intervals, and are taken to the

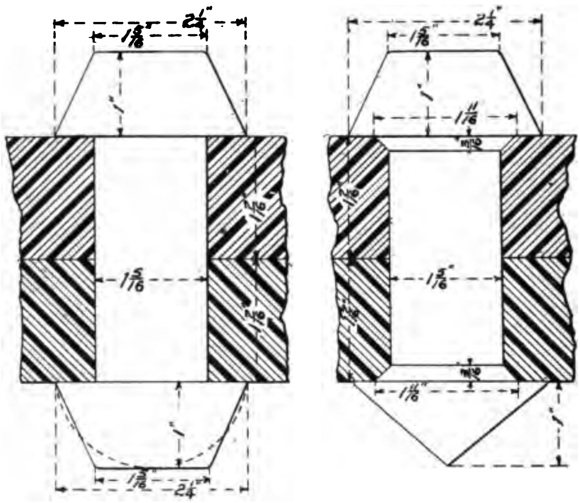


FIG. 64.

riveting machine, where the butt joints are riveted. The complete courses are next riveted together and all seams calked inside and outside. We have then a cylindrical shell, ready to receive the combustion chamber and furnaces and the three plates in each head.

We now go back to the plates which require flanging.

Flanging Plates.—After a very careful shop inspection of these plates, which is necessary on account of the trying work they have to undergo, the dimensions are laid out, as previously explained. The superfluous material outside of the flange edges is sheared off roughly, leaving a margin to be finished by pneumatic or hand chipping, after flanging. The straight edges are planed

to size. Curved plates are then bent, and all plates are now ready for flanging.

Most of this work can be done by hydraulic flanging machines, but some of it, especially at the ends where three plates join, must be drawn out and finished by hand. Tweddell's universal hydraulic flanger, built in this country, is generally used for progressive flanging, and the hydraulic flanging press, for die flanging at one heat; or, sometimes, the universal flanger only is used for both kinds of flanging, the different female dies being bolted to the bed plate. Plates to be flanged are heated to a bright cherry-red, and only so much of the plate as is necessary to make the flange. The length of flange that can be turned by a machine, at one heat, depends on the skill of the workman and on the convenience of the shop appliances, but about six feet can usually be turned, eight feet being rarely exceeded. From six to eighteen inches can be turned at one stroke of the ram.

When flanging the openings for the furnaces in the lower head sheet, one at a time, the fire in the flanging furnace is built up in a circular form, so that only the part to be flanged will be heated. By this arrangement, the other flanges, which have already been turned, will not be heated on the side next to the new flange and thus weakened. Where all the openings are flanged at the same time, the whole plate must be heated.

Great care must be used not to work the plates after the red heat has disappeared, as the dangerous effects of working steel at a *blue heat* have been thoroughly shown. Before the plate has lost its red heat, it must be returned to the furnaces and reheated. After the flanging has been completed, the plates are heated and straightened, and the flanges squared and smoothed. Several heats may be necessary. During the flanging operations, with their unequal heating, severe strains have been set up in the plate, which must be removed before it can be used with safety. This is done by *annealing*. Our specifications require that all flanged plates must be annealed after flanging.

Annealing.—This consists in heating the whole plate uniformly to a bright red in the annealing furnace, and then removing it to the floor of the boiler shop where it is allowed to cool gradually. The annealing furnace is usually built of fire brick and has a grate for a soft coal fire at one end, and doors, through which the plates are run in and out, at the other end of a brick hearth. The

products of combustion pass over the whole length and breadth of the hearth, and are discharged through ducts at the door end of the furnace. It takes from two to three hours to heat the plates to the required temperature, with a good hot fire, and about the same time to cool.

Shaping Top Head Plates.—Knowing now the general operations which all flanged plates must undergo, it will be necessary to note a few additional points only in the shaping of the curved top head plate.

The plate having been laid out, two tack holes are drilled in the middle of the bottom part, using the centers of rivet holes already laid out, or of a rivet and a brace hole. The plate is now rolled to a curvature of 3 feet 7 inches radius, excepting, of course, the lower $12\frac{49}{64}$ inches, and the upper $8\frac{1}{2}$ inches, which remain

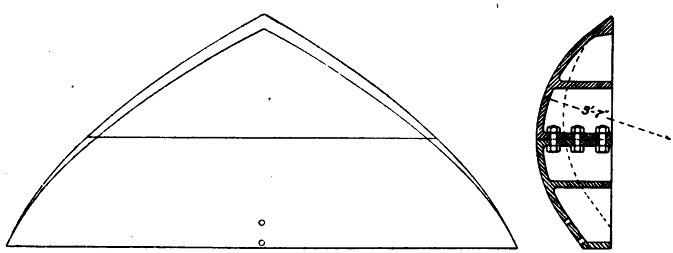


FIG. 65.

straight. Meanwhile, a *former block*, for flanging the edges of the plate, has been cast and made. This former block, Fig. 65, is usually made in two parts for convenience in fitting, as the shrinkage of the casting is uncertain. The parts are bolted together after adjustment, liners having been put in, or some of the material of the faces having been planed off, as required. The casting is about $1\frac{1}{2}$ inches thick and is strengthened by ribs. At the lower straight part of the head plate, the flange must be turned at an angle of 90°. As the plate curves in towards the shell, the flange angle gradually becomes smaller until it is zero at the top of the plate. The side edges of the casting are, therefore, beveled from 90° at the bottom to nothing at the top, as shown in the plan view. Two holes are drilled in the casting through which the head plate can be bolted to the former while flanging each heat.

The hydraulic press is used to turn the first 7 or 8 inches, but

the rest must be flanged by hand. For the latter, the ordinary sledges are insufficient, and, therefore, an anvil, or other heavy ram, is swung from the roof of the boiler shop and driven by three or four men against the plate. It has been found that, owing to the great weight of these thick head plates, the cast iron former, although comparatively light, will stand the heavy blows of the ram. When the flanging has been finished, the plate is annealed.

Assembling Parts and Riveting Boilers.—The assembling and riveting of the shell has already been described. The next step is to fit the sheets of the heads into this shell. In a single-ended boiler, the back head can be fitted and riveted at once, but in a double-ended boiler, only the fitting can be done, as the combustion chambers must be put in from both ends. It should be noted here that all riveted joints in the several parts of a boiler are *calked* before the joints are made inaccessible by fitting in the other parts. Thus, the inside seams of the completed shell are carefully calked before the heads and combustion chambers are fitted in. Before fitting and riveting flanged plates, the surface of the joint or flange, if greasy, is cleaned with concentrated lye or sal-ammoniac, in order to have good metallic contact.

The three plates of the head are laid on the floor of the shop, adjusted to the proper circle, and then bolted together through the tack holes, any disagreement in the laps of the flanges being corrected, so that these may be metal to metal. The rivet holes in the upper and lower edges of the middle plate and a few tack holes in the flanges of the three plates are now drilled. The top head plate is next bolted in place on the shell, then the bottom, and finally the middle plate, care being taken that the cardinal points agree with those marked on the shell.

Where the corners of the flanges of two sheets meet the shell, there are three thicknesses, and in order to make a good and tight fit, it may be necessary to heat the plates, by applying thick pieces of red hot iron, and then to bring them together with heavy hammers. The joint is shown in Fig. 66, the middle head sheet being tapered at the upper end of the flange on each end.

The plates are now taken down and all burrs removed. The tube holes in the middle sheet, and holes for braces in the other sheets are then drilled, as well as the rivet holes for the vertical angle iron stays.

The tube holes are drilled in a radial or other vertical drilling

machine, the spindle being fitted with a special cutter. A very efficient form of this cutter, Fig. 67, consists of a mandrel A, into the lower end of which is fitted a sliding center B backed by a spring. The hollow cylindrical cutter D slips over the lower end of the mandrel, and is held in place on the pins C by a bayonet catch. There are three cutting edges or teeth in the lower part of D. When the hole is to be drilled, B is placed in the center punch mark and, as the mandrel and its cutter are fed down, the center is gradually pushed up into A, until the metal of the plate has been cut through. The cutter is thus held centrally and the hole is cut in the exact position required. The change in the cylindrical cutters required for the different sizes of holes for ordinary and stay tubes can be made easily. The holes for stay tubes are drilled $\frac{3}{32}$ inch less in diameter than the tapping size. All tube holes are slightly rounded at the edges.

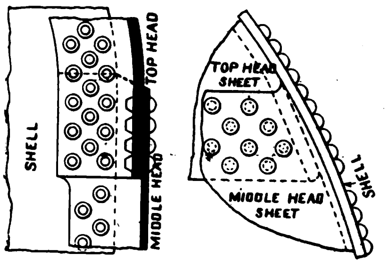


FIG. 66.

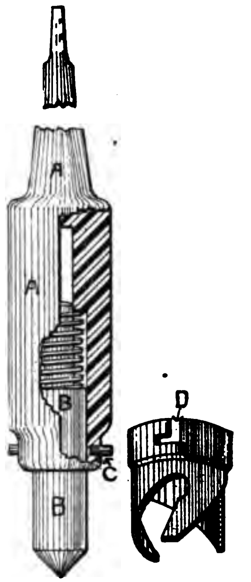


FIG. 67.

Meanwhile, the combustion chamber plates and the furnaces are fitted together and rivet holes in flanges drilled, in the same general manner as just described for the head sheets. Holes for the tubes, braces and angle iron rivets are drilled in the front plate of this chamber (which is the back tube sheet). The holes for the screw stays in the back plate of the combustion chamber of one end of a double-ended boiler are now drilled; the corresponding holes for the opposite chamber are not drilled until later. In single-ended boilers, these holes are not drilled until the combustion chambers are in place. The joint between the flat top and side plates and the flanged back tube sheets is shown in Fig. 68.

The top and side plates are lapped, the lap of the top plate, between A and B, being drawn down to fit in between the lap of the side sheet and the flange of the back tube sheet. The joint between the flat side sheet of the combustion chamber, the flanged back tube sheet, and the flanged back end of the wing furnace, shown in Fig. 69, is made steam-tight by drawing down the edges of the flanges of the tube sheet, and requires careful fitting.

In the boiler under consideration, there are four combustion chambers, each with two furnaces. The two furnaces and the tube sheet, after fitting, are riveted together, the vertical angle

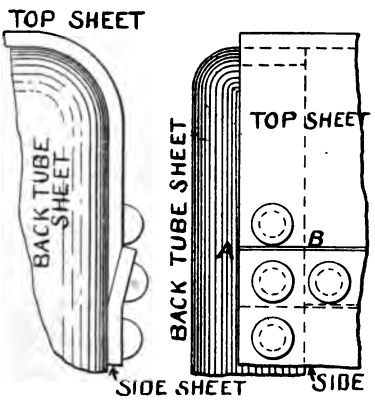


FIG. 68.

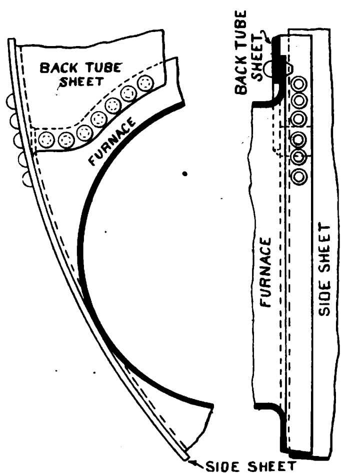


FIG. 69.

iron girder in the middle of the sheet having been riveted on. The sheets forming the top, sides, and bottom of the chamber are next riveted together and to the tube sheet and furnaces. The curved angle iron girders are then riveted to the bottom sheet. These girders are needed only for that part of the sheet which is not braced by the screw stays. The crow's foot for one of the braces between the furnaces is also riveted on. The combustion chamber is now closed by riveting on the back plate. Holes for the screw stays between the two combustion chambers are drilled in one chamber only.

The girders, Fig. 70, which brace the flat top of the combustion chamber, are now put in place. These are made of two flat plates, the lower edges of which are stepped to fit on the top and side

14

plates, as shown. These plates are riveted together with thimbles between them. Small clamp plates are fitted over the tops of the girder, and the whole is secured to the combustion chamber by bolts, which are screwed through the top sheet and have nuts at each end.

In some boilers, like those of the "Indiana" class, the top of the combustion chamber is curved, as shown in Fig. 71. The girders are then formed of curved angle irons riveted to the curved top, thimbles being set in between the girder and the top to avoid two thicknesses of plates next to the fire. At the lower end of the curve, the girder is riveted to a *gusset plate* A, which in turn is riveted to an angle iron on the back end in a single-ended boiler, as shown in the figure, or to the girder of the opposite combustion

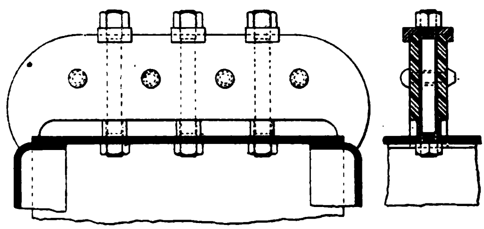


FIG. 70.

chamber in a double-ended boiler. The joint between the three sheets at the top corner is shown at B, the flanges of the top sheet and the tube sheet being drawn down to a tight fit.

In the gunboat and locomotive types of boilers, where there is a large flat top to the combustion chamber, hanging braces are usually adopted, as shown in Fig. 72. These braces are flattened out at top and bottom, and riveted to the boiler shell and top sheet of combustion chamber.

The two combustion chambers for one end having been completed, they are blocked up on a truck, and held together, in the position they will occupy in the boiler, by temporary braces running across the front of the tube sheets and bolted to these through the tube holes. The holes for the screw stays between the chambers are now drilled through, using the holes already made in the side of one combustion chamber as guides. These holes are then threaded with a continuous tap through both sheets, the stays screwed into place, and the nuts set up.

The combined chambers are next run up to the shell of the boiler, hauled into place by tackles running through from the other end of the boiler, and jacked and blocked to the proper height inside of the shell. The combustion chambers at the other end of the boiler are put in and centered in the same manner.

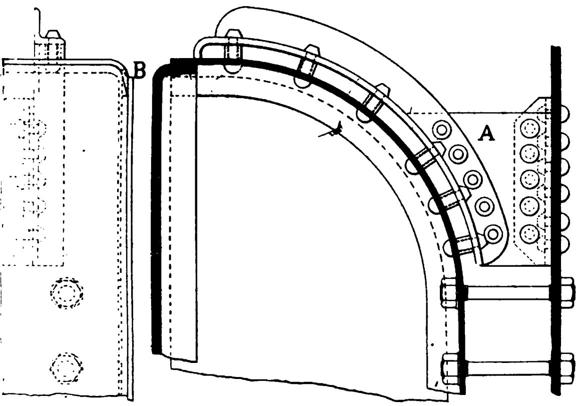


FIG. 71.

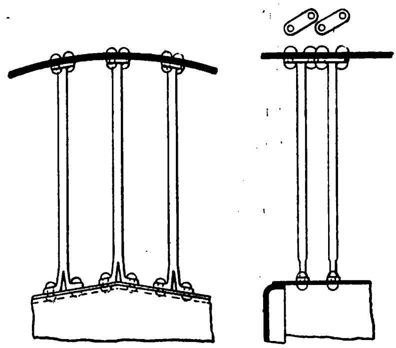


FIG. 72.

The bottom or furnace sheet of each head is then slipped into place; should the furnace ends not enter the holes easily, they and the combustion chambers are slightly shifted. The other two sheets of each end are next bolted in place, and then the holes for the screw stays are drilled and tapped in the sides and backs of the combustion chambers, using the holes already drilled in the shell as guides for the outer side holes. The holes in both plates are tapped with a single continuous tap, as before.

All screw stays for the combustion chambers have raised threads, 12 to the inch, and are fitted with nuts, see Fig. 73. Where the stays are not square with the plates, the nuts are set up on beveled washers. The threads of stays should be calked where they leave the plate.

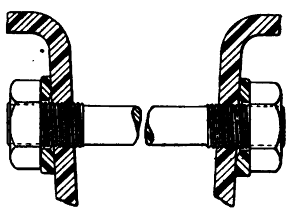


FIG. 73.

The combustion chambers being now permanently fixed in their correct positions, the rivet holes in the flanges of the head sheets, in the edges of the top and bottom sheets, and in the furnace ends are drilled, using the holes in the outer or lapping sheets as

guides. The rivets can then be driven and all seams calked inside and outside.

The next step is to put in the tubes. While assembling the boiler, care must be taken to have each pair of tube sheets parallel. The holes for the stay tubes must be tapped to form a continuous thread to suit that on the tube ends. To do this, a long bar is fitted with two taps, the cutting portions of which are about two inches further apart than the tube sheets. The leading tap has a plain thread following the cutting part. As the bar is inserted from the front, the thread in the combustion chamber sheet is cut first and, when the parallel part of that tap is entering, the other tap begins to cut the thread in the front tube sheet. The parallel part of the leading tap will, therefore, act as a guide for the other tap, and a continuous thread will be cut. The tubes are screwed into place by Stillson wrenches, worked from the inside of the boiler, until the ends project into the combustion chamber about $\frac{1}{8}$ inch. This end is then expanded and beaded over, as already explained. The ordinary tubes are now pushed through both holes from the front, a man in the combustion chamber guiding that end into its hole by means of a bar. The tubes project about $\frac{1}{8}$ inch at each end, and are expanded at both ends and beaded over at the back end, either against the sheet or into a recess, as already explained. Ferrules, if they are to be fitted, are put in after the hydraulic test of the boiler.

The braces are now put in place. These are the upper and lower through braces, and the diagonal and crow foot braces between the combustion chambers and front heads.

All of these braces are made of steel without welds and, where they are screwed into the plates, the ends are upset and threaded. Fig. 74 shows the details of the fitting of the diagonal and through braces, and Fig. 75, those of a crow foot brace. The threaded end of this brace is the same as that of the through braces; at the other end, it is forked and pinned to a crow foot riveted to the combustion chamber sheet. This arrangement distributes the load over a larger space of the comparatively thin plate of the combustion chamber. The holes in the plates have already been drilled and are then tapped for the Navy standard thread. The body of the upper brace shown is $2\frac{3}{4}$ inches, and the threaded ends, $3\frac{1}{4}$ inches in diameter. There are inside and outside nuts of forged steel or wrought iron, which are set up against the plates

directly, or on washers. In the boiler shown in Plates VII and VIII, no washers are used for the upper through braces, because these pass through two thicknesses of plates.

Formerly, the outer nuts of the upper through braces were set up and the ends of the brace allowed to project. In the "Kearsarge" and later designs, the thread is cut away on the outside of the nut, forming a chamfer, and, when the nut is set up to place, the end of the brace is riveted over into the nut. Where the braces do not come square with the plates, as in the diagonal

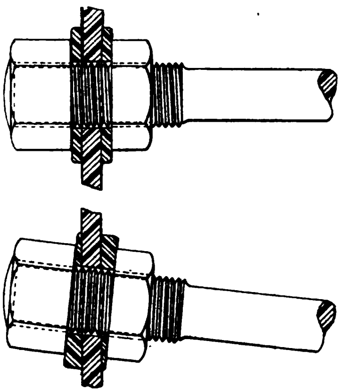


Fig. 74.

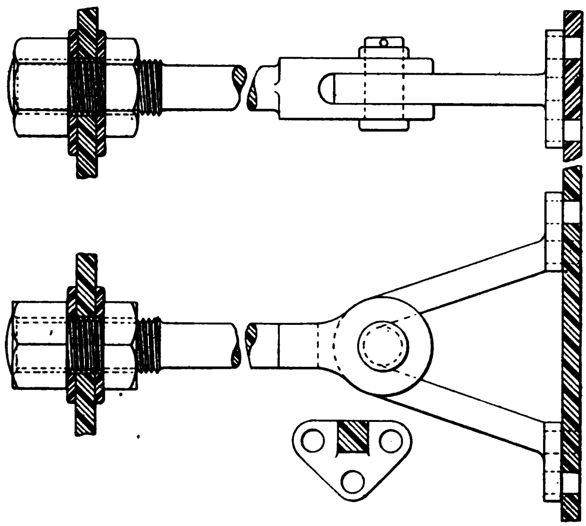


Fig. 75.

braces around the lower manholes, beveled washers are used to bring the bearing surfaces of the nuts square with the thread, as shown in Fig. 74. In the braces at the top of the lower wing manholes, the back end is forked, and fits over and is pinned to the crow foot riveted to the furnace flanges. These forks are solid with the brace, not welded on, and the sectional area through the eyes must not be less than that of the cylindrical part of the brace. They are secured at the front end like the other braces.

When putting in the screw braces, the washers and nuts for the inside of the plates must be placed in proper order on the brace, before it is screwed into the second hole. After the brace has been screwed through both plates, the outside washers and nuts are put on and, with the inner nuts slacked back, are set

up hard to bring the brace in tension. The inner nuts are then set up hard on their washers.

Manufacture of Suspension and Corrugated Furnaces.—The following is the method used by the Continental Iron Works, the only makers of these furnaces in this country.

The steel plates of the different sizes and thicknesses, as they come from the rolling mill, are first rolled into cylinders of suitable diameters, and then lap-welded by passing the lap, at a welding heat, between rollers subjected to hydraulic pressure. The welded cylinders are then heated in a vertical furnace, which is fed by producer gas, and are removed, in a vertical position, to a vertical corrugating machine, where the corrugations are produced by continuous feed and many revolutions of the rolls. After completing the corrugations, the furnaces are flanged by machine

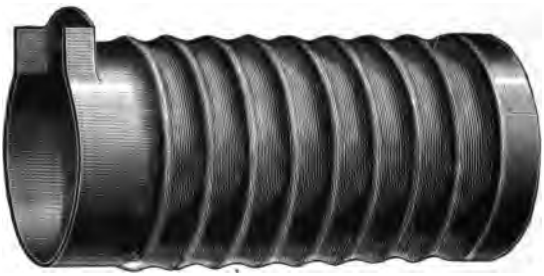


FIG. 76.

or hand work, as desired, to meet the required conditions, and next thoroughly annealed. They are then ready to go into the boiler.

Fig. 72 shows a finished suspension furnace with small flanges, as fitted for separate combustion chambers. This furnace is a removable one, the diameter of the straight part at the back being less than that of the corrugations. The diameter of the straight part at the front end is made slightly larger than that of the corrugations, to facilitate the entry of the flue into the furnace hole in the lower sheet of the boiler.

Manufacture of Purves' Ribbed Furnaces.[1]—As the thickness of the furnace is not the same throughout, the ordinary plain-rolled plate cannot be used. A steel slab of rectangular section is

[1] From D. B. Morison's paper on "Marine Boiler Furnaces," reprinted in the Journal of the A. S. N. E., Vol. V.

formed from the ingot under a hammer, and converted, by special roughing rolls, into a ribbed plate, 1¼ inches thick, which, after reheating, is passed through finishing rolls until the final required thickness is obtained. The thickness of the plain parts on each side of the plate is increased by one-eighth, to allow for the thinning which takes place during flanging. After shearing the edges and slotting one end to the shape required for the flanges, the plate is bent to a circular form by a special hydraulic press, and the edges then welded together by the insertion of a piece of steel called a "dutchman." The plain parts are welded first and the ribs afterwards. After annealing, the flue is made perfectly circular by a special hydraulic press. It is then flanged and again annealed.

Testing Boilers.—The boiler being completed, there remain only the manhole plates and other boiler fittings which are to be put on before the boiler is tested in the shop. Holes for pipe and other connections not used are closed by blank flanges for this test. This, as well as the other tests required, is carried out in the same manner for all boilers, so that no special description will be given for tubulous boilers.

The shop test is made before the boiler is painted or clothed, so that leaks can be noticed quickly. The boiler is filled quite full, and then heat applied to the water, by a steam connection, until the pressure, due to the expansion of the water, has reached the required limit. This is 90 pounds per square inch, by gage, above the working pressure for shell boilers, and one and one-half times the working pressure for tubulous boilers. If the boiler is tight, the test pressure can easily be obtained without heating the water to a temperature higher than 212° F., or the boiling point under atmospheric pressure. No explosion or dangerous rupture can follow so long as this temperature is not exceeded. During this test, the furnaces are gaged from time to time to detect any change in circularity, combustion chamber sheets are carefully watched to detect any bulging, tube and other joints inspected, and small leaks marked for correction later. In fact, the whole boiler is carefully examined until the test has been completed satisfactorily. Should many or serious leaks develop, another test may be necessary after they have been corrected. Meanwhile, the steam pipes and valves, the auxiliary engines, and all fittings and connections which will be subjected to the boiler

pressure, have been tested by hydraulic pressure to the same limit. The water pressure is obtained by filling the pipe or valve quite full, and then, by means of a hand pump, slowly raising the pressure.

After a satisfactory test, the outside of shell boilers and drums of tubulous boilers are painted with two coats of brown zinc and oil, and the boilers then lowered into the vessel.

After they have been secured in place, and all connections made, but before the clothing is put on shell boilers and on the exposed parts of tubulous boilers, the boiler and pipe connections are tested by *steam* to one and one-quarter times the working pressure. When all leaks have been made tight, the clothing and lagging are put on, and the boiler fronts are painted white.

The regulation test of boilers in commission has already been described in Chapter VIII. The testing of sample boilers for evaporative efficiency and other purposes is described in Chapter XVIII.

CHAPTER XIII.

TYPES OF TUBULOUS BOILERS.

General.—We now come to the various types of tubulous boilers, which, owing to certain constructive and tactical advantages, are gradually taking the place of shell boilers on cruisers and battleships, as they have already replaced them on torpedo boats and destroyers.

The demand for increased speeds, consequent on the introduction of the torpedo boat, required and led to increasing steam pressures and a reduction in the weight of the steam generators and other equipments of the ship. The shell boiler satisfied the first requirement until pressures above 200 pounds per square inch were used, but, as its weight increased rather than decreased with the pressure, other things being equal, it could not comply with the second requirement. A revival of the use of tubulous boilers resulted, followed by a rapid development of this class of boilers and a very large increase in the number of types. In the following pages, only such types as have been installed on our ships will be described, with a short reference to the principal ones used in other navies.

The general advantages of the tubulous over shell boilers are: (1) less weight and generally less space for the power generated, (2) greater suitability with safety for high pressures, (3) better ability to stand forcing, (4) greater facility in shipping and installation, and (5) fitness for raising steam quickly without danger, owing to the small quantity of contained water.

The smaller weight of tubulous boilers is chiefly due to the small quantity of contained water. The average weight of water in the shell boilers of our Navy is about 32 per cent of the total weight of the boiler installation, omitting uptakes and smoke pipes, while that in tubulous boilers, on our torpedo boats and destroyers, is about 17 per cent. There is a wide range in this figure for the various types of tubulous boilers, about 13 per cent being the lowest, and 26 per cent, the highest.

The "Cincinnati" had formerly six shell boilers, four double and two single-ended, the total weight of which, ready for steaming, without uptakes and smoke pipes, was 464.57 tons. The weight of these boilers without water was 311.01 tons. The present installation of eight Babcock and Wilcox boilers weighs 224.7 with water, and 190.78 tons without water. Of the total saving in weight, 239.87 tons, practically one-half, 119.64 tons, was due to the smaller quantity of water carried in the tubulous boilers. The weight of contained water is about 33 per cent of the total shell boiler weight and about 15 per cent of the total tubulous boiler weight.

Another example is the installation on the coast defense vessel "Monterey." There are two single-ended shell, and four Ward tubulous boilers. The two shell boilers have a total heating surface of 2905, and a total great surface of 88 square feet. The corresponding figures for one Ward boiler are 2970 and 74 square feet. The two shell boilers weigh 46.4 tons without water, the water in them weighing 25.6 tons. One Ward boiler, of practically the same heating surface as the two shell boilers, weighs 14.9 tons without water, the water in it weighing only 2.4 tons. Based on heating surface, it would take eight shell boilers to replace the four Ward boilers, and the total weight of the boiler installation would then be increased 218.8 tons.

Comparison between the locomotive type of shell boilers and the Yarrow tubulous boiler may be made in the case of the sister vessels "Havock" and "Hornet," British torpedo boat destroyers. The weight of the boiler installation (locomotive) of the "Havock" was about nine tons more than that of the "Hornet," and the heating surface only about five-eighths that of the Yarrow boilers. The trials, under the same conditions of sea and weather, gave a speed of 26.1 knots with an air pressure of 3.5 inches for the "Havock," and 27.3 knots with 1.6 inches for the "Hornet."

The chief differences between the various types of tubulous boilers are in the arrangement and shape of the tubes. The tubes are arranged either in separate sections or in nests, and they are either straight or curved. Straight tubes are generally of large diameter and nearly horizontal, and curved tubes, of small diameter and nearly vertical. Another difference, now disappearing, is in the location of the discharge of the generating tubes into

the steam drum. In most types, this is below the water level in the drum, while in a few the discharge is well above.

Vertical tubes may be of smaller diameters than horizontal ones, as the steam bubbles have a freer delivery to the steam drum. In a horizontal tube, the bubbles will rise to the top of the curve and, unless a strong current is established in the central portion of the tube, which will carry the bubbles along with it, their movement upwards along the concave surface of the tube will be very much slower. In a horizontal tube of small diameter, the current will not be as strong as in one of larger diameter. The earlier form of the Babcock and Wilcox boilers, such as is fitted on the British gunboat "Sheldrake," has tubes which are only $1\frac{13}{16}$ inches in diameter, while a later form, fitted on the "Espiègle," has $3\frac{3}{16}$-inch tubes. Comparative trials of these two vessels showed that the evaporation from and at 212° F. was materially greater on the "Espiègle," although the ratio of heating to grate surface is only 28, while on the "Sheldrake" it is 36.

Regarding the fifth advantage mentioned above, some explanation is necessary. While steam can be raised quickly, say in 30 minutes without danger, it cannot be utilized in starting the main engines, when the latter are cold, under one or one and one-half hours at the very least, and then only when a great emergency justifies this. In order that the engines may be in condition to start on twenty or thirty minutes' notice, they must be kept warm and the main auxiliaries running, and to do this, more boilers will be required than are necessary for auxiliary purposes, whether the vessel has shell or tubulous boilers.

By keeping the engines warm, as on blockading or other continuous duty where they are to be used on short notice, the advantage of raising steam quickly in tubulous boilers can be realized, and with economy in the total coal expenditure. For, as steam can be raised from cold water in tubulous boilers with less coal than in shell boilers, owing to the smaller quantity of water to be heated, a large proportion of the total grate surface of the former need not be kept in use. To have vessels, fitted with shell boilers, continuously in a condition to move on short notice, the water in the idle boilers must be kept hot, say at about 210 or 220° F., by the hydrokineters, or, the fires must be lighted and a low steam pressure maintained by spread fires. If the water is kept hot, steam may be raised to the working pressure in from 40 to 65 minutes, while with spread fires, moderately heavy and

kept clean, the time may be reduced to from 20 to 45 minutes. The coal expenditure to maintain the former condition will be considerably less than that necessary for the latter.

An interesting comparison of the times necessary to raise steam is given by the British cruisers "Hyacinth," fitted with Belleville, and "Minerva," fitted with shell boilers. These sister ships were ordered to run from Gibraltar to Portsmouth, England, at the highest speed possible, the fires in the idle boilers to be started on signal at an unknown time after 4 P. M. on July 17, 1901. Two out of the eighteen Belleville boilers and one out of the eight shell boilers were under steam for auxiliary and other purposes. Fires were laid in all boilers, and the engines thoroughly warmed and ready by 4 P. M., at which time the average temperature of the water in the idle boilers of the "Hyacinth" was 94¼°, and of the "Minerva," 122½° F. The signal to start was made at 4.27. In 53 minutes the "Hyacinth" was going ahead at ⅞ of the power maintained during the greater part of the run, while in 49 minutes, the "Minerva" had reached nearly her full power. The time was, therefore, practically the same, although the shell boilers had the advantage of 28¼° in temperature of the water.

According to experiments made in the German navy,[1] it requires about 14 tons of coal to raise steam from cold water in tubulous boilers, having a grate surface of 547 square feet; to keep shell boilers of the same grate surface hot by the hydrokineters, so that steam may be raised in the same time, about 6 tons per day must be expended. After lying-to for two and one-third days, the vessel fitted with tubulous boilers would, therefore, be kept ready more economically than the one with shell boilers.

Owing to the higher steam pressures and the smaller amount of water carried, tubulous boilers require a more highly-trained and skilled force for their management. And, owing to the increased number of units, which means an increased number of parts and fittings, a larger force is necessary to preserve and care for them.

[1] From "The Water Tube Boiler Question in the German Navy," by Köhn von Jaski, reprinted in the Journal of the A. S. N. E., Feb., 1902.

CHAPTER XIV.

BABCOCK AND WILCOX BOILER.

The general description of this boiler, which is a sectional, straight-tube one, has already been given in Chapter I, and by referring to Plates III and IV, when necessary, the following additional information will be understood.

The generating tubes T and the lower tubes H over the furnace, which form the greatest part of the heating surface, and the side tubes I′ and boxes I, which are outside of them, are inclined at an angle of 15 degrees to secure a continuous circulation in one direction. The side headers or uprights at the four corners are vertical.

These tubes are arranged in vertical sections, each consisting of a number of straight tubes expanded at their ends into forged steel headers. The headers for the generating tubes are sinuous or corrugated in shape, Figs. 80 and 81, and extend down to the mud box M in front, and to the top of the bridge wall in the back. The headers for the side tubes and boxes have straight sides, Fig. 77, and extend down below the level of the grate. The side headers have each only one vertical row of tubes and boxes; the tubes stop near the top of the furnace, being replaced below that by square forged steel boxes, which are fitted close to each other to form the sides of the furnace. These boxes are of sufficient thickness to withstand the wear and tear of the fire tools, and, being filled with water, no brick or tile lining on the fire side is necessary.

The tubes in the sinuous headers are 2 inches in outside diameter, except the lowest ones, which are 4 inches. As the corrugations of adjacent headers fit into each other, and as the tubes are staggered in the headers, direct paths or lanes for the escape of the gases of combustion are prevented.

The mud box M is 6 inches square, and runs along the bottom of the sinuous headers and between the two side headers. It is connected to each of these headers by short 4-inch tubes. Diagon-

ally at the back is the top connection box M′, similar to M and similarly connected to the headers. This method of connecting the upper ends of the rear headers with the steam drum is not generally used in the latest boilers. In the boilers of the "California," "West Virginia," "St. Louis" and others, the rear headers rest upon an I-beam, which is supported by the rear uprights,

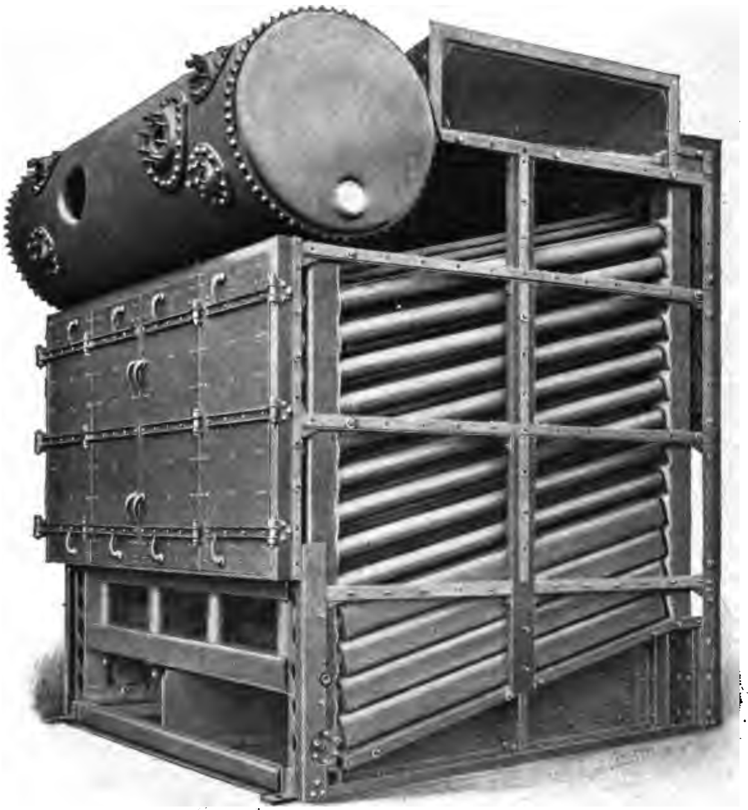


FIG. 77.

and they are made one corrugation longer, Fig. 81, than the corresponding front headers. The return tubes connect this extra corrugation on each header direct to the steam drum, and the connection box M′ is, therefore, not necessary. In the boilers for the cruiser "Atlanta," Fig. 77, another box, similar to M, is placed

below it at the level of the dead plate of the furnace front, and is connected to M and the side headers by 4-inch tubes. The vertical connecting tubes form the divisions between the furnace doors. This arrangement is no longer used and was fitted on the "Atlanta" only.

Extending across the front of the boiler is a horizontal steam and water drum Y, which is connected to the top of the front headers by short tubes, and either directly, as explained above, or indirectly through M′, to the top of the rear headers by the upper or return tubes. The connecting and return tubes are all 4 inches in external diameter. Each section has, therefore, an independent inlet and outlet for water and steam. The center of the drum is on the normal water line of the boiler, so that changes in the volume of water carried have the least effect on the level shown in the gage glasses. In the earlier form of this boiler, as fitted on the "Annapolis" and "Marietta," the steam drum is at the back, and the construction of the headers, which are straight, is somewhat different. By placing the drum in front, all valves and other fittings are more accessible.

In the headers are handholes opposite the tube ends, through which the tubes can be examined, cleaned, plugged, or renewed. These holes are covered by faced plates, which are drawn to faced seats by means of a dog, stud and nut, the joint being made on the inside of the header by a thin gasket. The renewal of a tube is easily performed, no special tools being required, the usual cape chisel, hammer and expander being sufficient. The operation is the same as for the ordinary tubes in a shell boiler, except that the tube ends need not be beaded. In the "Marietta" type, brass screw plugs are fitted over the ends of the 2-inch tubes in the front header; copper ferrules should be used to protect the threads in the header, when any work is done through these holes.

When there is not time to renew a tube, the ends may be closed by conical cast iron plugs, which are driven into the tube with a hammer. The plugs furnished with the boilers are drilled and tapped on the large end, so that they can be withdrawn easily by means of a bolt, nut and dog. It may be mentioned that the renewal of a tube does not require very much more time than the plugging.

The outside of the tubes of each row are cleaned by a steam or

air jet through the dusting doors D, as already mentioned. These doors slide up and down, and can be opened and shut with the end of the cleaner. As the seat for each door is beveled, the tendency is to make an air-tight joint by wedge action when the door falls.

The boiler being full to steaming level, the circulation is as follows. The vapor formed in the tubes and some water rise to the back ends of the tubes and into the rear headers. From the top of these, they pass through the horizontal return tubes into the steam drum. Here they strike the curved baffle plate, the steam passing around its ends into the steam space, and the water being

FIG. 78.

FIG. 79.

deflected down into the water space. From the drum, the water passes down through the short connecting pipes into the front headers and enters the lower ends of the tubes, thus completing the circuit.

The bottom valves *m* are attached to the lowest parts of the front side headers, and through them the boiler can be drained completely.

DETAILS OF CONSTRUCTION.

As the construction of this boiler is very simple, not much need be said.

The Drum.—This is made of steel, the shell being of one plate with a longitudinal joint. It is built under the same general specifications as are shell boilers. The heads are formed in a single heat, by hydraulic presses, to a spherical surface, the radius of which is equal to the diameter of the shell.

The manhole is flanged in the shell plate or head, with a stiffening ring of sufficient thickness to form, with the edge of the plate, a seat one inch wide for the gasket. Figs. 78 and 79 show a drum head with manhole. The plates for the latter are of compressed steel, 11 by 15 inches, faced to fit the oval hole.

FIG. 80.

FIG. 81.

Headers.—The corrugated headers are formed from square blanks of open-hearth sheet steel, ½ inch thick. In a single heat, they are squared on a mandrel and corrugated on both sides by hydraulic presses, and, after annealing, they pass to multiple tools that bore and face the handholes, other multiple drills being used for the boring of the tube holes. By the use of this form of header or manifold for connecting the tube ends, a perfectly

flat tube sheet is obtained, and which requires no stays or braces, as the sides of the header are sufficient for that purpose for any steam pressure required. In the new design of rear header, that portion of the extension, which forms the tube sheet for the return tube, is pressed out or pocketed, so that the tube seat will be at right angles to the axis of the tube. The ends of the headers are closed by $\frac{3}{8}$-inch steel plates welded into place.

One form of header is shown by Fig. 80, and the later design

FIG. 82.

by Fig. 81. In the latter, the tubes are arranged in clusters of four, each cluster being directly opposite a handhole 5 inches square. In the older form, all of the 2-inch tubes are not directly in line with the handholes, and the latter are oval. It will be seen that in the new form, the tubes can be examined, cleaned, or renewed without difficulty.

The side headers or uprights are made in a similar manner, except that they are not corrugated and that the tube sheet portion is pressed out as shown in Figs. 77 and 83. The lower end

of each side header is forged, from a single block of steel, into a box-shaped bottom with a projecting stud, two inches in diameter. The rough box is then put in a lathe, the bottom faced off square, leaving a large fillet around the stud, and a thread cut on the

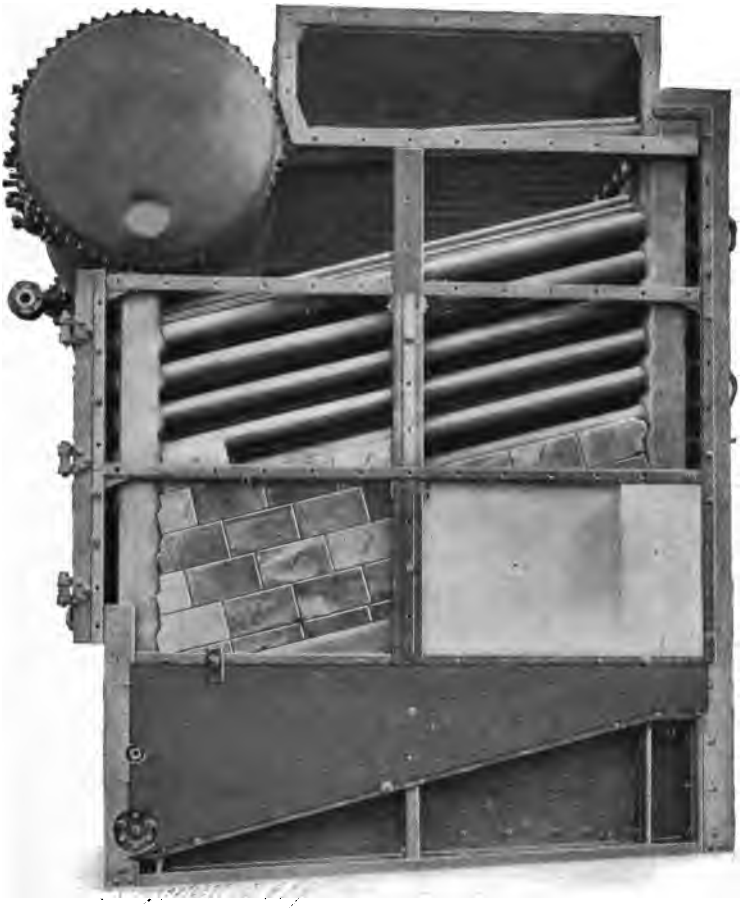


FIG. 83.

stud. This system insures strength and, as the bolt and the bottom of the box are one and the same piece, there is no possible chance of leakage. The header is completed by welding on the box at the bottom and welding the flat top into place.

Erecting the Boiler.—The sections, one of which, with the rear

end in the foreground, is shown by Fig. 82, are built up, care being taken that the two headers are parallel during the expanding of the tubes, and that the latter project one-half inch beyond the hole at each end. The sections are then placed on wooden horses, to give them the required inclination of 15 degrees to the horizontal and their approximate final location. The triangular foundations at the side are next put in place, and the side sections bolted to them by nuts on the studs, these studs passing through holes in the ends of each foundation, as shown for the rear end in Fig. 83. The mud boxes and the short tubes connecting them to the side headers are next put in place, and the tubes expanded. When putting in these and the other short connecting tubes, care must be taken that they project one-half inch beyond the hole at each end, and that these projecting ends are swelled or trumpeted after the tubes have been expanded. The expander is put in and worked through the handholes in the headers. The short connecting tubes, which have previously been expanded into the top of the front mud box, are now expanded into the headers over the furnace. The tubes, connecting the rear header and the top connection box, where this is fitted, are expanded into place through the handholes in that box. The steam drum is now lowered into place and the ends of the connecting tubes expanded. The upper return tubes, when expanded into place, complete the pressure parts of the boiler.

After a satisfactory hydraulic test, the tile work, iron frame for the casing, the clothing of $\frac{1}{4}$-inch asbestos mill-board and 2-inch magnesia blocks, Fig. 83, the sheet iron casing, Plate III, and the remaining outside parts of the boiler are secured in place.

For convenience in shipping, especially with small boilers, the steam drum is left off, although the boiler may be entirely cased in. Frequenly, as in the case of the boilers for the "Denver" class of cruisers, the steam drum is placed in position and the connecting tubes expanded after the boilers are secured in the vessel.

Overhauling the Boiler.—The tubes can be cleaned on the inside, by straight brushes, or, if necessary, by scrapers. The baffle over the furnace is likely to warp and need renewal after some time, and may then necessitate the removal of some of the 4-inch tubes.

Spare Parts and Tools.—The tubes being straight and of commercial size, only the usual allowance of tubes need be carried. A

few side boxes, short and long connecting tubes, which may be cut from the commercial 4-inch tubes, and handhole plates and dogs, complete the allowance of special parts necessary.

Ordinary tube expanders of the proper sizes, and an expander, fitted to work from the farther end of the short connecting tubes, some iron tube plugs, and an extractor should be on board.

CHAPTER XV.

NICLAUSSE BOILER.

This is another sectional boiler with straight tubes, which has been installed on several of our recent battleships and cruisers.

Plates IX and X show this boiler fitted for the closed fire room system of draft, as on the battleship "Maine." The heating surface consists of a series of sections, each consisting of a vertical corrugated header R, into which are secured a number of inclined tubes T. The tops of the headers are connected to a steam drum Y. The sides and back of the furnace F are of brick work. The air supply above the grate can be regulated by the small doors *g*. Baffle plates B, B, are fitted along the tubes and force the gases to take a longer way to the uptake U. The sides, front and back of the upper part of the boiler are covered with the casing C and doors E, lined with magnesia and asbestos.

While the general appearance of this boiler is similar to the one just described, it will be noticed that there are no back headers and no upper return tubes, that the tubes incline down from the front to the back, that the headers are always vertical, and that there are no side headers and tubes. To understand the reason why some of these fittings are not necessary, the design of the headers and tubes must be examined. Fig. 84 shows the ordinary and a combination header, of which the former only need be noticed now. Fig. 92 shows a section of an upper tube in place and of the connection of header to drum, and the direction of the circulation. The whole tube is called a Field tube, and consists of the outer, or *generating tube*, and the inner, or *circulating tube.*

The header has corrugated sides and is divided longitudinally, by a diaphragm, into two unequal chambers, the smaller one being for the down-coming currents of water, and the larger one for the up-going currents of water and steam. The separation of the currents is kept up to some distance inside of the drum by means of a funnel, or a baffle plate. The headers being vertical, the three holes for each Field tube are at an angle.

The generating tube is closed at the back end, and has an elongation at the header end. This elongation is either separate, as in

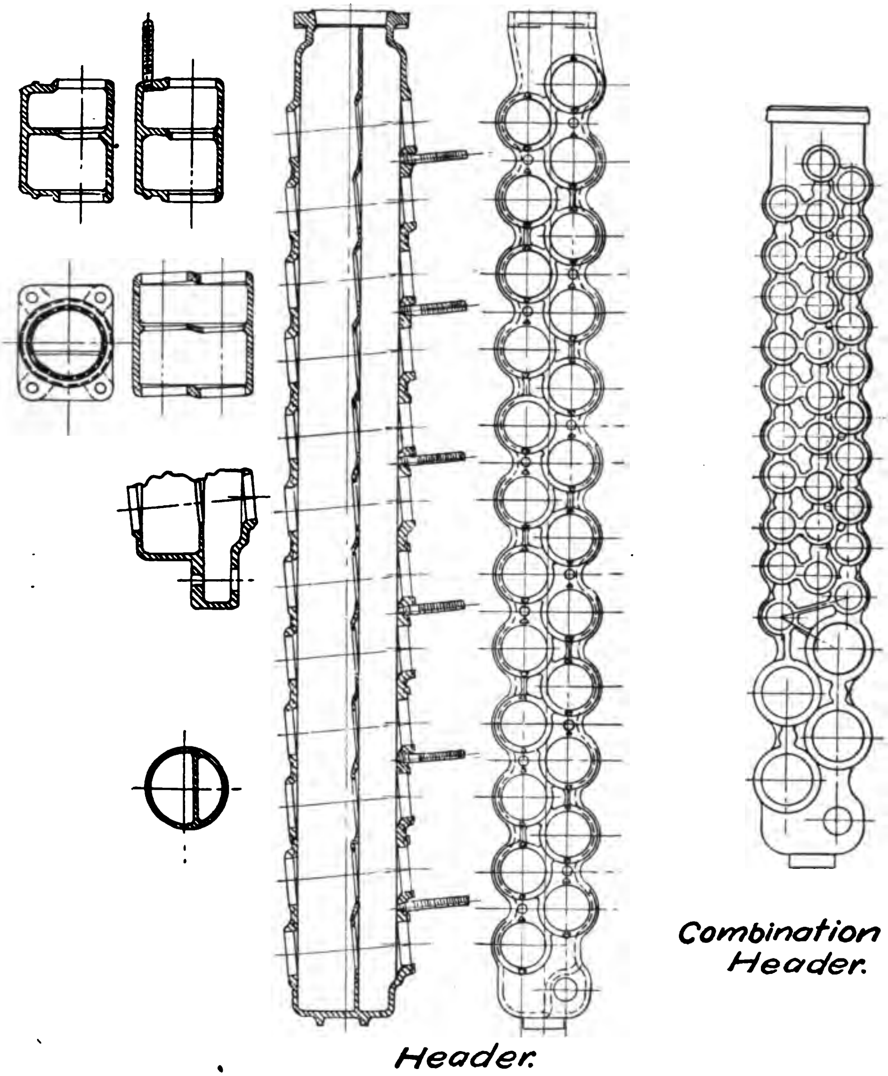


FIG. 84.

Fig. 92, and is then called a *lantern,* or in one piece with the tube, as in the later forms on the "Georgia," "Virginia," etc., Fig. 94, and has openings in it through which the generating and circulat-

ing tubes are in independent communication with the large and small chambers of the header, respectively. The circulating tube stops some distance from the closed end of the generating tube and is open at that end. It is partly cut away where it passes through the water chamber to allow water to enter it. At the front or outer end it is secured to a cup plug, which closes the outer end of the lantern, or generating tube.

The joints at the front and back of the header are made steam-tight by cones on the generating tube and the lantern, the details of which will be explained later. To make the whole tube still more secure, a dog is slipped over the stud on the front of the header, its feet bearing against the bottom of the cup plugs of adjacent tubes, and set down by a nut. There is no joint in the diaphragm, the holes in it being slightly larger than the tubes.

The boiler being full to steaming level in the drum, the circulation is as follows. The water in the generating tubes will be heated first, will pass out of each tube into the large chamber, and ascend into the drum near its center in the form of steam and water, being replaced by the cooler feed water coming down from the drum into the outer chamber, and thence into the circulating tubes and through them into the generating tubes. The feed water is discharged into a light steel box fitted in the drum, and to which is connected a trough, which extends nearly the whole length of the drum. The trough is fitted with a series of baffle plates, for the purpose of causing precipitation of any foreign matter in the water, and also to increase slightly the temperature of the water before it finds its way into the headers.

The drum is provided with the usual boiler fittings and, in addition, with an automatic feed regulator. The bottom blow connection is close to the bottom of the headers and in front of them, one form being shown in Fig. 93, and another, at m, in Plates IX and X.

The generating and circulating tubes are free to expand independently of each other, the back ends of the former being supported in a cast iron frame, one for each section. The bottom of this frame rests and can slide on a metal plate on top of the bridge wall, as the tubes expand and contract. As the headers are corrugated and the tubes staggered, the course of the gases of combustion is not directly upwards, but is around the tubes. The tubes are all of the same size for the large ships, $3\frac{1}{4}$ inches in

external diameter, as in the "Maine." For smaller ships, like the "Nevada," the combination header shown on the right of Fig. 84 is used. Here the two lower rows only consist of 3¼-inch tubes, the others, in three vertical rows, being $1\frac{9}{16}$ inches in external diameter. Owing to this arrangement, the tubes in the two left-hand vertical rows are not staggered. With these exceptions, there is no difference between the combination and the large tube headers. The outside diameter of the circulating tubes is $1\frac{19}{32}$ inches for the large, and $\frac{15}{16}$ inch for the small generating tubes.

Fifteen sections are usual in one boiler, the height of the sections or elements varying in different boilers. The tubes are partially cleaned from the front of the boiler by a steam or air jet directed between the sections, the intervening space being about ⅝ inch. With the horizontal baffles B, B, soot will probably collect in the corners of the two upper ones, and must be removed by hand.

The steel casing, which forms the outside of the boiler, is lined on the sides and back with fire brick as high as the lowest rows of tubes, the bridge wall being heavier than the sides. Above this, the casing is double, the space being filled with the standard magnesia. On the sides, additional clothing is provided, which is protected by fire tiles above the brick work. The front of the casing consists of small removable doors, or of swinging and sliding doors, as in Plate IX.

The furnace fronts consist of fire brick work, the furnace openings being made of four plates of cast iron. The plates are fitted with grooves, so that they can easily be renewed when distorted and burned. The fire and ash pit doors open inwards on trunions, so arranged that they will close by the pressure from the inside in case of the rupture of a tube. An ash pan is fitted below the level of the air duct in the ash pit.

The boilers on the "Maine" are arranged for the closed fire room system, and on the "Nevada" and later ships, for the closed ash pit system of forced draft. The dampers in the air ducts of the "Nevada's" boilers have no safety connection to the furnace doors; they must, therefore, be closed before the furnace doors are opened when under forced draft.

DETAILS OF CONSTRUCTION.[1]

Headers.—These are made of malleable iron or pressed steel, the latter being used in all ships, except the "Maine" and "Nevada."

If the header is of malleable iron, the casting is first thoroughly cleaned, all irregularities dressed off, and then the thickness of the walls carefully calipered to detect thin spots. The steel headers are inspected for cranks and other defects. The headers which are satisfactory are then swung on a lathe, and the top flange faced sufficiently to bring the corrugations of all headers into the same relative position to this flange. The correct length of the header is then determined from this flange, the necessary amount being cut from the foot pieces of the cast headers and from the bottom of the steel headers. The large hole at the top of the header is now bored on the same lathe, the hole being made cone-shaped, one inch deep and at an angle of 10 degrees.

The header is next secured to the carriage of a heavy boring mill in an inclined position, the top hole fitting in a rest which is elevated, so as to bore out the tube holes at an angle of 6 degrees to the axis of the header. The holes are bored conical by one tool to within $\frac{1}{20}$ inch of their finished sizes, the front hole being slightly larger than the back one. The header is then put on trestles, keeping the same inclination as before, and the holes reamed to finished size by a pneumatic-driven reamer, swung loosely. The holes for the blow-off connection are then drilled and reamed conical to their finished sizes, the header being horizontal. The latter is next thoroughly cleaned and all sharp edges removed, and is then ready for the insertion of the tubes.

If the header is of steel, it is made from a lap-welded tube, $9\frac{5}{8}$ inches in diameter, which is first squared over a former and then corrugated, by a heavy hydraulic press, over a corrugated cast iron mandrel placed inside. This mandrel is made in two parts so that the diaphragm can be placed between them. The diaphragm is a separate sheet of flat steel, corrugated at the sides and slightly wider than the cast iron mandrel. Along the corrugations of the diaphragm there are raised points about 6 inches apart. After the tube holes are drilled in the diaphragm, it is put between the two parts of the mandrel, the three parts are

[1] The cuts and most of the data are from Mr. Geo. B. Hartley's paper in the Journal of the A. S. N. E. Vol. XIII.

then shoved into the squared tube and the whole put in the press. Here the corrugations are formed in the header, and, at the same time, the diaphragm is pressed into the header along its whole length, the attachment being made still firmer by the points. The cast-iron mandrel is now broken up and the pieces removed. Holes are now drilled in the two flat sides of the header, their size being such that enough metal is left around each hole to form the flanges necessary for the tube joints. These preliminary holes are drilled with the header at an angle of 6 degrees, as before. The same inclination is preserved when the header is next put in a hydraulic press, where all tube holes on one side are flanged

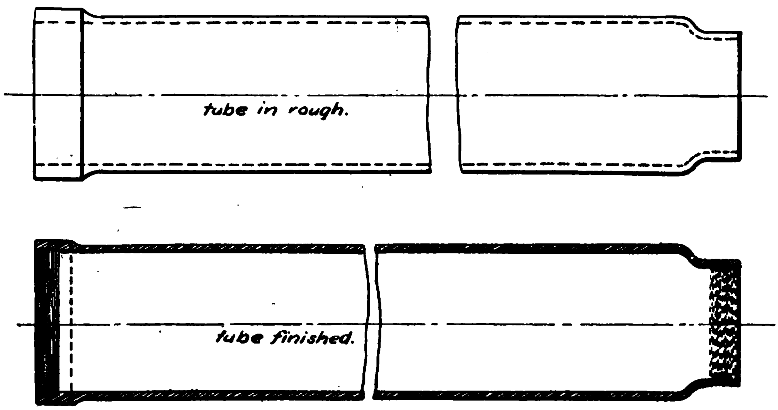


FIG. 85.

outwards at the same time by a series of pins, one for each hole, which force semi-spherical forms of the correct diameter through the drilled holes. The header is then turned over, the forms placed in the holes, and the tube holes on that side flanged. The machining of the tube holes and the rest of the header is the same as for the cast headers.

Generating Tubes.—These are of mild steel, seamless, cold-drawn, and vary from No. 6 to 10 B. W. G. in thickness, the front ends being upset and the back ends swaged. Fig. 85 shows a tube in rough, as received from the manufacturer, for the "Maine" and "Nevada."

This tube is first put in a double turret lathe where the swaged end is threaded on the outside, sixteen threads to the inch. The outside of the upset end is now turned to a cone to within

$\frac{1}{20}$ inch of the finished size, the inside tapped with left-hand threads, sixteen to the inch, and next faced off to give the correct length of tube by gage. The tube is then put between the centers of a special grinding lathe, where a fine emery wheel, revolving rapidly in the opposite direction to that of the tube, grinds the cone to finished gage size, a micrometer feed and fixed taper

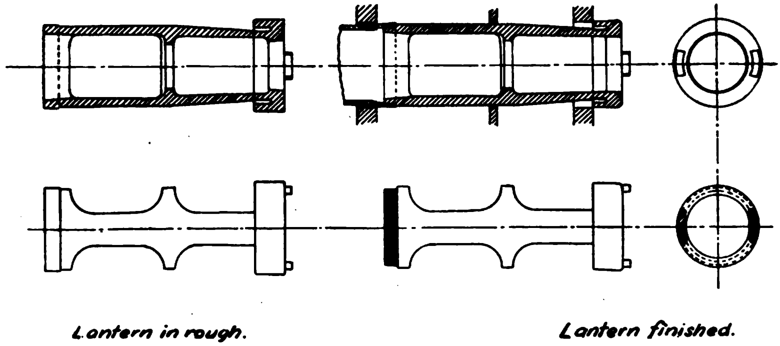


FIG. 86.

attachment on the wheel insuring uniformity in these cones. The smaller end of the cone is next slightly rounded, to prevent its cutting the tube hole when put into place in the header. The tube is now finished, see Fig. 85, and is next clamped to the assembling table, ready to receive the lantern.

Lanterns.—These, for the "Maine" and "Nevada" are separate from the generating tube, and are of malleable iron, the lantern in rough being shown on the left of Fig. 86.

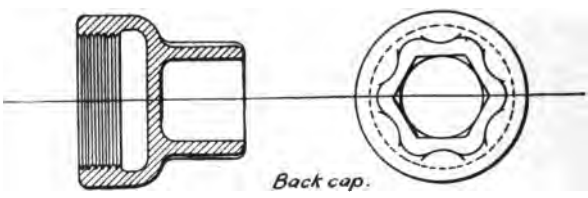


FIG. 87.

The lantern is clamped, large end out, in a revolving chuck on a turret lathe, and the hole reamed and tapped with double threads, six to the inch. The angle of the tap is rather large, so that the joint with the cup plug, Fig. 91, can be made quickly. The large pitch of the threads prevents injury to them and gives broad bearing surfaces. This threaded end is next

screwed on the plug center of another lathe, and the small end of the lantern turned and threaded to fit, accurately and tightly, the thread on the inside of the upset end of the generating tube. The outer surface of the large end of the lantern is now turned and coned similarly to the generating tube. It will be noticed that there is a recess under the cone of the lantern; this permits the cone to be compressed. Then the finished lantern, Fig. 86, is screwed into the tube, white lead being used to make the joint; when this has been done, the distance between the cones on the lantern and on the tube must be exact to the smallest fraction. The tube and lantern are from now on handled as one tube, which is next closed by the cap on the back end.

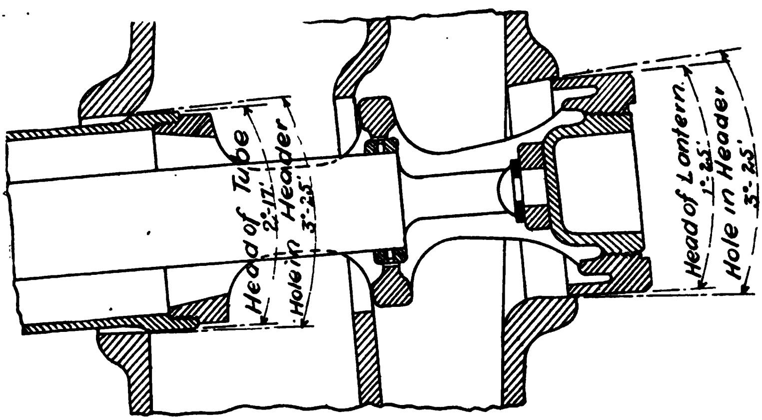


FIG. 88.—Section through Tube, Lantern, and Header. Showing respective positions when Lantern Cone begins to bear.

Back Caps.—These are drop forgings, Fig. 87, which are reamed and counterbored below the thread, and accurately threaded, sixteen to the inch. When this cap has been screwed on the swaged end of the tube, the latter is complete and ready to be put into the header, the circulating or inner tube being put in after the outer tube has been secured.

Fitting-Up a Section.—The header is bolted in a vertical position on the testing blocks, and the support for the back ends of the tubes put in place. The studs for the dogs are then screwed in, and the tube holes in the header and the cones on the tubes covered with a non-corrosive mixture, composed chiefly of graphite. This

mixture is used as a protection only and not for the purpose of making the joints tight.

Each generating tube is now put in its hole and pushed through until the back end has entered the support. The cone on the tube is then on the point of entering the cone hole in the back of the header, while the cone on the lantern has already entered the hole in the front of the header about $\frac{3}{16}$ inch, as is shown in Fig. 88. The tube is next forced in by means of the *inserting tool,* Fig. 89, until the back joint is made, the lantern cone compressing sufficiently to permit this. As the front cone is farther in its hole than is the back one, it follows that the joint in front is made so soon as the back joint is completed. When the tube is home, the hole in the diaphragm is almost closed by the partition in the lantern.

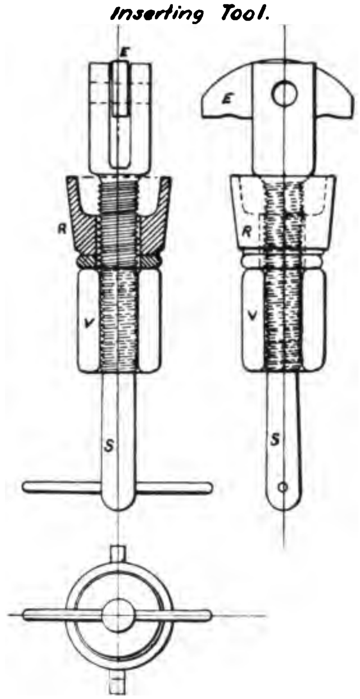
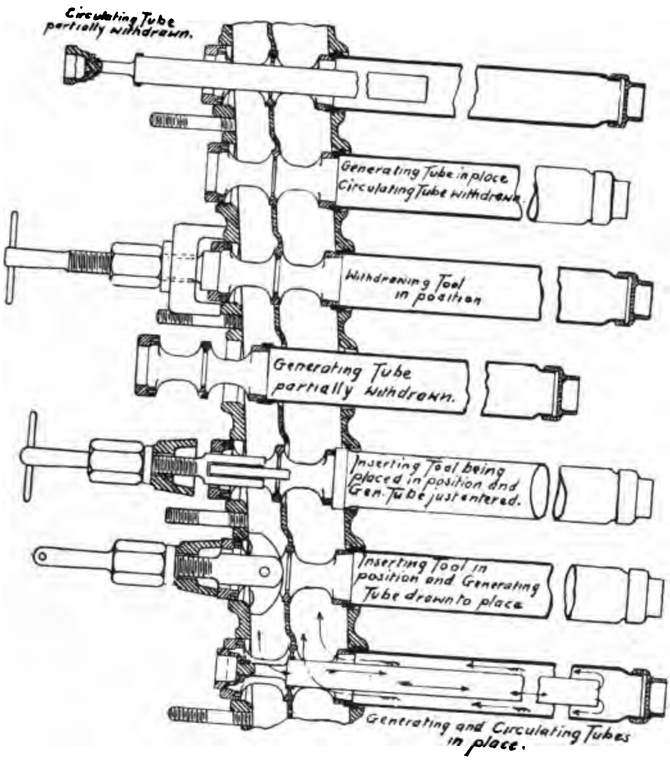


FIG. 89.

The inserting tool consists of the threaded spindle S, on one end of which is the swivel cross piece E. R is a cup-shaped dog, a little smaller in diameter than the head of the lantern against which it bears, and V is a nut screwed on S and bearing against R. The method of inserting and using this tool will readily be understood by referring to the fifth and sixth rows of tubes in Fig. 90. When setting up nut V, too much pressure must not be applied, as this would make more than the necessary point bearing. Experience has shown that the wrench used should not be over 24 inches in length, and the pressure applied at the end of it not over 30 to 40 pounds.

Fig. 88 shows the different angles of the cones and holes by means of which tight joints are made. Both holes in the header have the same angle, 3 degrees 25 minutes. The cone in the tube

has a taper of 2 degrees 17 minutes, while that on the header has only 1 degree 25 minutes, but has its inner circumference elastic. The surfaces of the holes, on which the joints are made, are near the large ends of the holes in the header and, therefore, are not injured when the tube is put in or pulled out, as the latter then bears against the small diameter of the holes only.



Method of inserting and removing the Tubes.

FIG. 90.

When the generating tube is secured, it will be at an angle of 6 degrees to the horizontal, the header being vertical, and the circulating tube can then be put in.

Circulating Tubes.—These are of steel, varying from No. 18 to 24 B. W. G. in thickness, and are made of two strips, the two

seams thus made giving some rigidity to the thin tube. Secured to the front end of each of these tubes, which stop at the diaphragm, is a small lantern, which has a screw cup plug riveted to its front end, Fig. 91. This plug is threaded to fit the thread on the inside of the front end of the lantern on the generating tube, and the whole circulating tube is then screwed into place, the threads being covered with the non-corrosive mixture mentioned above.

Testing the Completed Section.—After all tubes have been put in and secured in the header, the section is ready to be tested. As we have already seen, there are three steam-tight joints for each tube and a fairly tight one in the diaphragm. To test the former, the holes in the header for the bottom blow connection are plugged, and a blank flange, with water and air cocks, is fitted over the

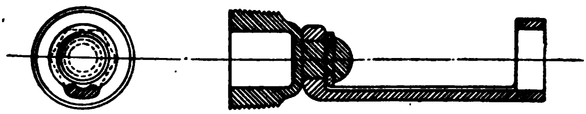


FIG. 91.

large hole at the top. A water pressure of 500 pounds per square inch is then applied and no leaks must appear. For this test, it is not necessary to put on the tube dogs, as sections have been put under a pressure of over 900 pounds and no tubes were forced out. The difference between the areas of the front and back ends of the tube is so small that the unbalanced pressure is overcome by the slight adhesion of the cone joints.

The Drum.—The drum is built of boiler steel and under the same requirements and inspection as are shell boilers. The heads of the drum are usually flanged out so that machine riveting can be used for the seams. At the bottom, where there is large opening for nearly the whole length of the drum, a heavy strengthening plate, usually 2⅜ inches thick, is riveted to the shell along its length. This header plate, see Figs. 92, 96 and 97, must be heavy enough to have the necessary strength after the cone holes for the header connection have been cut in it. These cone holes, which are drilled and reamed in the header plate before it is riveted to the drum, consist of the large hole for each header connection, coned to an angle of 10 degrees, and four bolt holes, coned to an

angle of 12 degrees 11 minutes. It will be remembered that the hole in the top of the header is coned to an angle of 10 degrees. As the four bolt holes in the flange of the header have no connection with the steam, they are not coned.

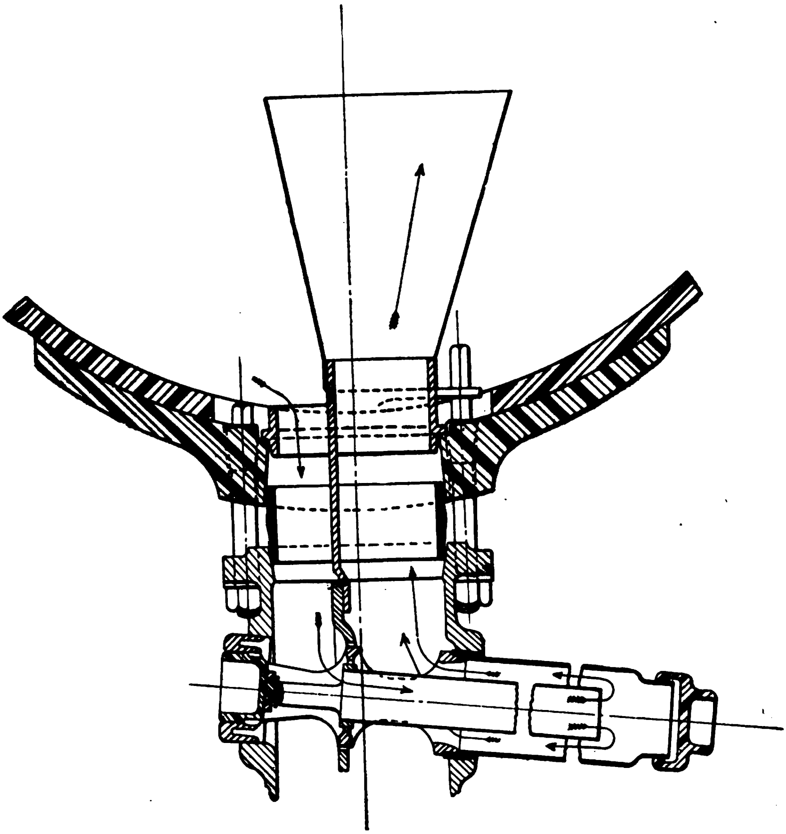


FIG. 92.

The holes for the various fittings are cut in the drum, and the nozzles for them fitted and riveted in place, care being taken that the nozzles for the feed valve and feed regulator are at right angles to the cone holes in the header plate. After all the riveting and calking is finished, all holes are blank-flanged, and the drum is tested by hydraulic pressure to 400 pounds per square inch. If this is satisfactory, the blank flanges on the cone holes are re-

moved, and the drum is taken to and suspended over the erected boiler.

Erecting the Boiler.—The casing having been completed, the brick work around the furnace built in, and the side panels lined with non-conducting material, the necessary number of tested sections may be put in place, preparatory to securing them to the drum. When the sections are not put in as a whole, but are built up in the boiler, the supports for the back ends of the tubes must first be bolted in place next to the back casing. The section is then fitted up as before, except that each tube is guided into its hole in the back support by a long stick inserted in the tube.

The headers having been perfectly aligned and spaced, a double cone nipple, see Fig. 92, with an angle of 5 degrees 44 minutes, is

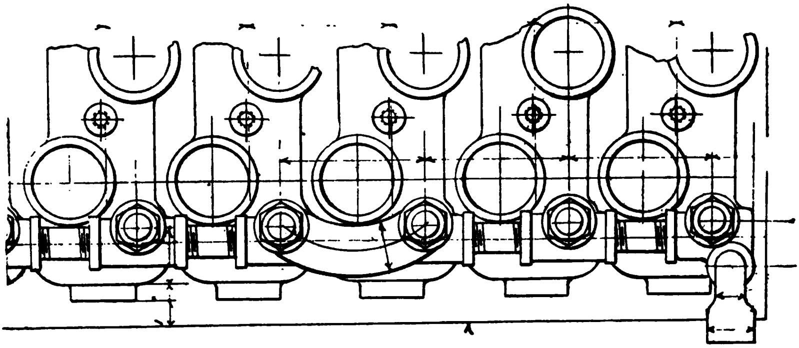


FIG. 93.

placed squarely in the cone hole at the top of each header, and the drum then carefully lowered on these nipples, so that they will bear firmly in both holes. The bolts, the cone head of which is tapered to an angle of 10 degrees 48 minutes, are next put in place from the inside of the drum, and the nuts set up uniformly against the flange of the header. The drum is thus drawn down to make steam-tight joints at the two points of contact of the nipple and at those of the cone heads of the four bolts, the principle being the same as that of the tube joints and depending on the difference in the angles of the cones.

The bottom blow connections, Fig. 93, are made next. These consist of extra heavy malleable iron fittings, connected to each other by threaded nipples. The connection to the front of each header is made by a double cone nipple, similar to that described

above, and the whole is drawn tightly into place by a long through bolt, which has a cone head at the back of the header and a cap nut with a faced bearing at the end outside of the fitting.

The boiler is now given a final hydraulic test of 400 pounds per square inch before leaving the erecting shop. If this is satisfactory, the internal fittings are put in the drum. One of these is the current separator on each header, which, in Fig. 92, is a malleable iron ring, with a diaphragm extending down to join the one in the header and a light funnel riveted to the top. In the later boilers, the separator consists of a diaphragm in each hole, which is bolted at the top to a division plate running the whole length of the drum, see Fig. 97. This division plate is bolted at the bottom to angle irons, which are in turn tap-bolted to the

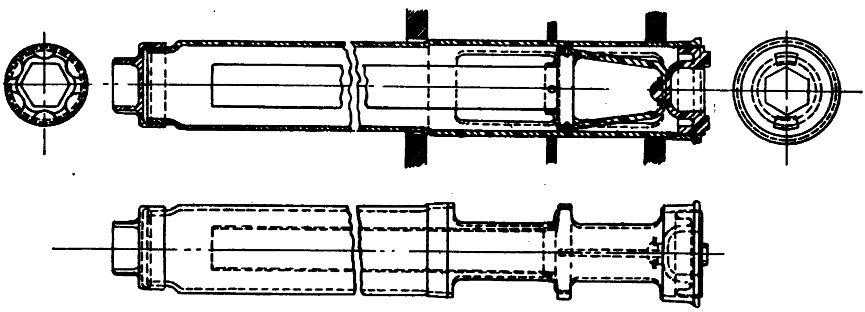


FIG. 94.

header plate between the holes. The curved top of this plate is stayed by a few straps to the side of the drum. Another internal fitting is the feed discharge box in the earlier boilers; or, as in the later ones, the curved baffle hood G for the feed, and a separate box U for the float, see Fig. 97.

The tested boiler with its internal fittings is now put in the vessel, or, if it is to be sent away, it is taken apart, and the several pieces shipped to and reassembled at their point of destination. To complete the boiler for steaming, after all connections have been made, the tube dogs are put in place and the nuts set up. In doing the latter, it must be remembered that the nut does not make the joint around the tube, as in a manhole plate, but that it serves chiefly to keep the joint made, and that for this purpose very little stress need be put on the stud.

New Type of Tube.—Instead of making the lantern of malleable

iron and separate from the generating tube, the construction adopted for all ships after the "Maine" and "Nevada" consists of one piece of tube only, as shown in Fig. 95, in which the upper view is a section looking down from the top of the header, and the lower one a side elevation. The lantern end of the tube is slightly larger and somewhat heavier than the part which is exposed to the fire, and has openings cut into it where it passes through the two chambers in the header. The machining of this tube is similar to that of the two-piece tube previously described, the lantern end being thick enough to permit the external cones and internal thread at the front end to be cut and finished. The plug for the small lantern is of steel and is recessed under the thread to permit the compression of the cones on the tube, and thus differs from the older construction. The small lantern consists of a narrow strip of steel, bent as shown, and pinned to the plug at the bend; the two ends are riveted to a flanged ring, which makes the partition inside of the generating tube between the two chambers. The circulating tube is secured to the central flange in the ring, as before. This construction is simpler than the older type, and, being of steel throughout, not so liable to rupture.

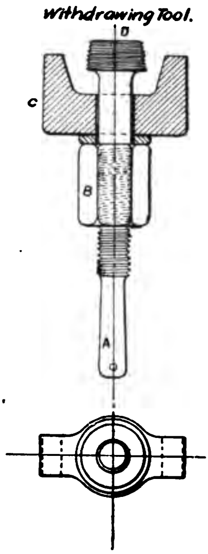


FIG. 95.

Removing a Tube.—Should a tube rupture or be burned, so that it can still be withdrawn without having to be cut, the circulating tube is first unscrewed and drawn out. Then the *withdrawing tool,* Fig. 95, is put in place, the plug D being screwed in the lantern, and the dog C and the backing nut B adjusted. A part of a turn given to B will break the joints, and the generating tube can be pulled out easily, as will be seen by Fig. 90, four top tubes. If the new tube is put in and secured with the inserting tool, as already explained, no mistake can be made, as the opening in the lantern must be up and down before the swivel cross piece will fall into position. Unless the opening is in this position, the sides or solid parts of the lantern will impede the circulation of the water and interfere with the free escape of the steam.

To renew a faulty tube in a boiler under steam, when it is not so

badly warped or ruptured as to require cutting, it will take from three to four hours with experienced men. This includes the time necessary for hauling fires, blowing down, filling boiler and getting up steam again. On the "Maine," several lower tubes in different boilers were badly ruptured and had to be cut off. The renewal of these tubes required very many more hours than the simpler case.

Leaky Tubes.—Should a slight leak occur in a tube end, no attempt must be made to stop it by setting up on the nut of the dog. A few light taps on a block of wood against the tube end will generally be sufficient, the nut being followed up just enough to make the dog bear well again. Should, however, this light tapping be insufficient, the tube may be set in a little harder, and then the slack taken up on the dog nut. As this extra setting-in of the tube will embed the tube in the cone in the header, this bearing must be made smooth with emery paper when through steaming.

Cleaning the Boiler.—Owing to the construction of the boiler, the tubes can be examined only by taking out the circulating tube, and can be cleaned only by removing the generating tube. When the boiler is blown down or drained, some water will remain in the lower end of each generating tube, which can be removed only by siphoning or by taking out the tube; either method is laborious and requires time, so that it is better and safer to keep the boiler entirely full of water when it is not in use.

When the boiler is to undergo the regular periodical inspection, the examination of the tubes should begin at the bottom, as the lowest rows are most liable to need cleaning. If as the examination progresses upward in any section, tubes are found to be clean of scale or other deposit, those above the clean row need not be opened. It is apparent that much labor will be required and much time needed to examine and clean thoroughly every tube in a boiler composed of 15 sections, each of 24 tubes, or 360 outside tubes in all, which means the careful handling of 720 tubes. With a battery of 24 boilers, 2 or 3 of which will always be under steam for auxiliary purposes, and 12 of which, at least, will be required for steaming, care will have to be exercised to so use the boilers that not too many will require thorough cleaning at the same time. As a rough estimate, based on the experience of other navies, this thorough cleaning will be necessary after 800 or 900 hours of steaming, and will require the services of 2 petty officers and about 5 helpers for at least 4 working days at 8 hours each for each boiler.

Spare Parts and Tools.—Besides the regulation allowance of boiler tubes, boiler and furnace fittings, a supply of plugs, lanterns and back caps for the tubes, double cone nipples and bolts for the drum connection, and nipples and bolts for the bottom blow connection should be required. A complete set of gages for all taper joints, cone nipples, connecting holes, etc., such as are used in the construction of the boiler, are necessary. Besides these, several inserting and withdrawing tools, and two friction clamps in each fire room, for holding a tube while removing the back cap, will be needed for quick work.

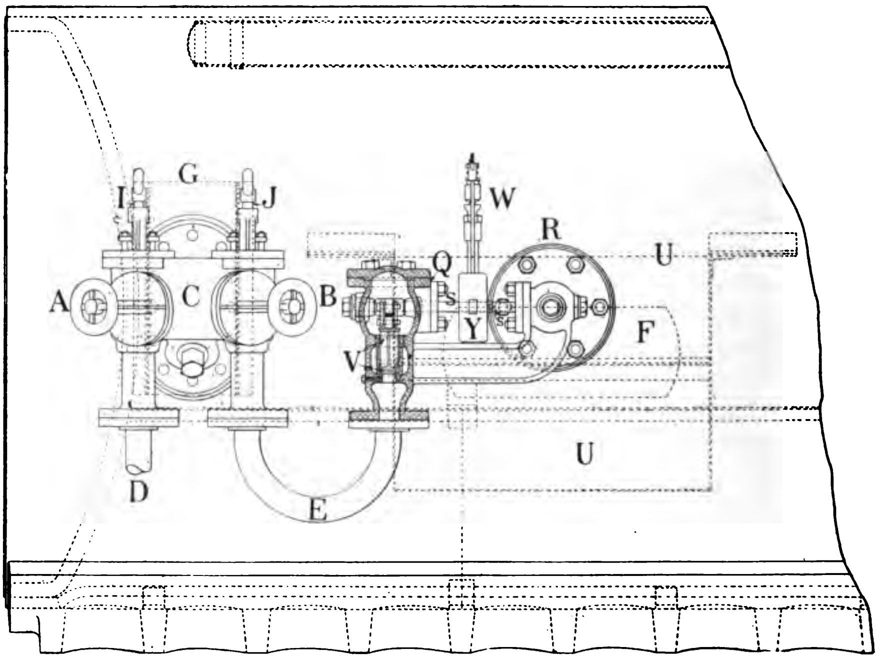


FIG. 96.

Automatic Feed Regulator.—This is shown, partly in section, in Figs. 96 and 97. In Plate IX the regulator is shown on the right hand side of the steam drum.

The chamber C, bolted to and opening into the sides of the drum, contains the auxiliary and main feed stop valves A and B and the corresponding check valves, the stems of which are shown at I and J. The auxiliary feed enters through the pipe D and passes

through its valves *directly* into the drum. The baffle hood G is fitted opposite to the discharge openings of the auxiliary and main feeds and directs the water downwards, as shown by the arrows. The main feed enters the regulating valve chamber Q at H, and, after passing the double regulating valve V, enters the pipe E, and thence, through its check and stop valves B and J, into the drum.

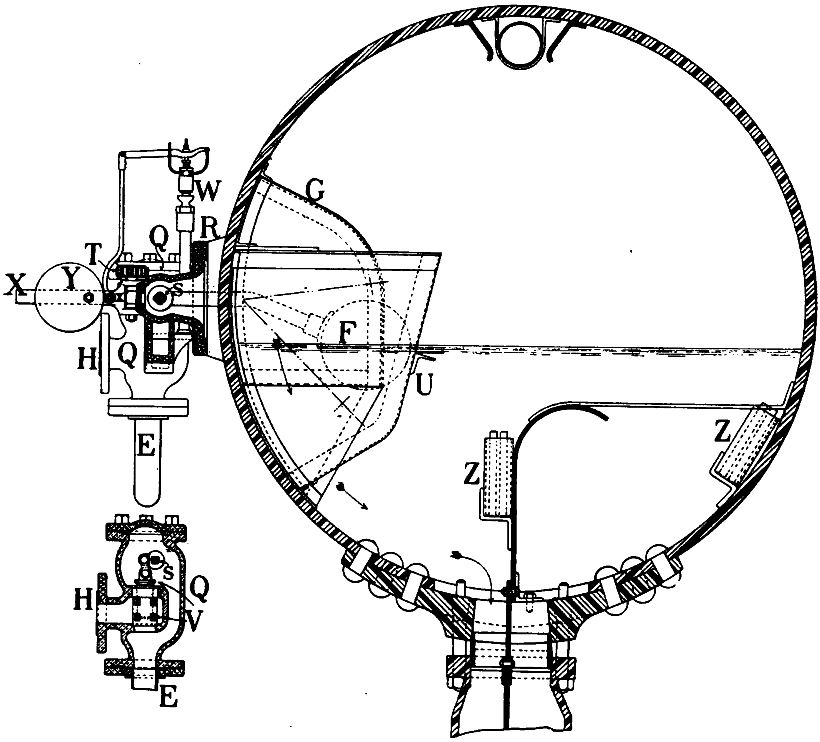


FIG. 97.

The automatic regulating device consists of the double valve V, outside of the drum, and a float F inside, the latter, as it rises and falls with the water level, closing and opening the former, by means of a shaft, bell cranks and levers, as shown in the seperate view of the valve. F is connected by a lever to the horizontal shaft S, which consists of two parts joined by a crank pin movable in slotted cranks. The junction of these two parts, which may be called the *float shaft* and *valve shaft,* is in line with the counter-weight Y, and cannot, therefore, be seen in the elevation, Fig. 96.

To crank X are connected the adjusting wheel T and its sliding screw block, the counterweight Y, and the lever of the low water alarm whistle W. A pin in the screw block on X engages in the slot of the crank on the valve shaft, and thus communicates the motion of F to V. A stuffing box and a cap nut form the bearings on which the float shaft oscillates inside of the casting R. The valve shaft is similarly fitted in chamber Q. The vertical shaft of wheel T is threaded at its lower end into the block, which can be raised or lowered in the slot in X. As the block moves, the pin moves with it, and changes the throw of the crank on the valve shaft, and, therefore, the lift of valve V. By turning wheel T, the proper adjustment can be made.

The open box U around the float provides a comparatively quiet body of water for F, and prevents violent working of the regulator.

CHAPTER XVI.

THE THORNYCROFT BOILER.

This boiler is of the curved and small-tube class, with the tubes arranged in nests, the first type of which, the "Speedy," Figs. 98 and 99, is fitted in the "Cushing," "Ericsson," and in the later torpedo boats of comparatively small power, like those of the "Davis," "Mackenzie" and "Shubrick" classes.

Speedy Type.—The pressure parts of this boiler consist of a large steam drum Y and two smaller water cylinders M, M, the centers of the latter being about on a level with the grate. Each lower cylinder is connected to Y by a nest or series of small, curved generating tubes and by a large pipe B, called the *downtake,* or *down-comer.* The generating tubes, which form the heating surface of the boiler, are so curved at the top that they enter the drum above the water level; special provision must, therefore, be made to establish a circuit for the water. This is done by means of the downtakes B, which connect the bottom of Y with the tops of M, outside of the boiler casing.

About the middle of the length of the generating tubes, the two inner rows on each side are curved inwards, so as to form the top of the furnace or combustion chamber. The sides of the second row of tubes touch those of the first row, thus forming a closed wall, except at the bottom, where the first row, for the distance WX, is bent inwards. The spaces thus made at the bottom form the only openings between the furnace and the rest of the tubes. The two outer rows on each side are similarly curved to form a wall, but, in this case, the openings are formed at the top and connect the uptake U with the rest of the tubes. Each nest of tubes consists, therefore, of an inner and outer wall, and a number of tubes which do not touch each other. The gases of combustion from the furnace enter the openings WX, rise between the generating tubes to the upper openings, and through these into the uptake. While this lead of the gases *along* the tubes is not as efficient as that *across* the tubes, it is retained in all types of this boiler on account of certain advantages in the circulation of the

water. The tubes, the ends of which are simply expanded into the drums, are very long, giving a large heating surface, and their curvature gives sufficient elasticity to allow for considerable expansion and contraction. The tubes are of steel, seamless-drawn,

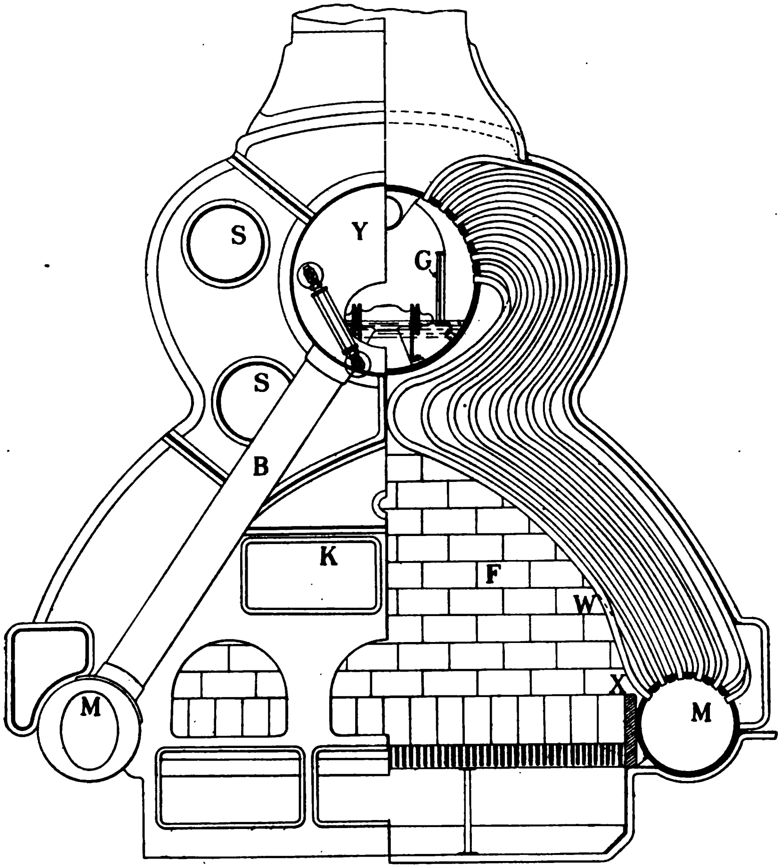


FIG. 98.

and vary from 1 inch to $1\frac{1}{4}$ inches in external diameter, those forming the furnace walls being generally larger than the others.

The back of the furnace, the inside lining of the furnace front, the sides of the furnace near the level of the grate, and the dead plate, are all of fire brick. A light steel casing, lined with standard non-conducting material above the brick work, surrounds the tubes on the front, back and sides, and joins the uptake. It will

be noticed from Fig. 99, that a considerable portion of the drums and both downtakes are outside of the casing, and that this part of the boiler, therefore, serves no useful purpose as heating surface, although it does as a means of circulation.

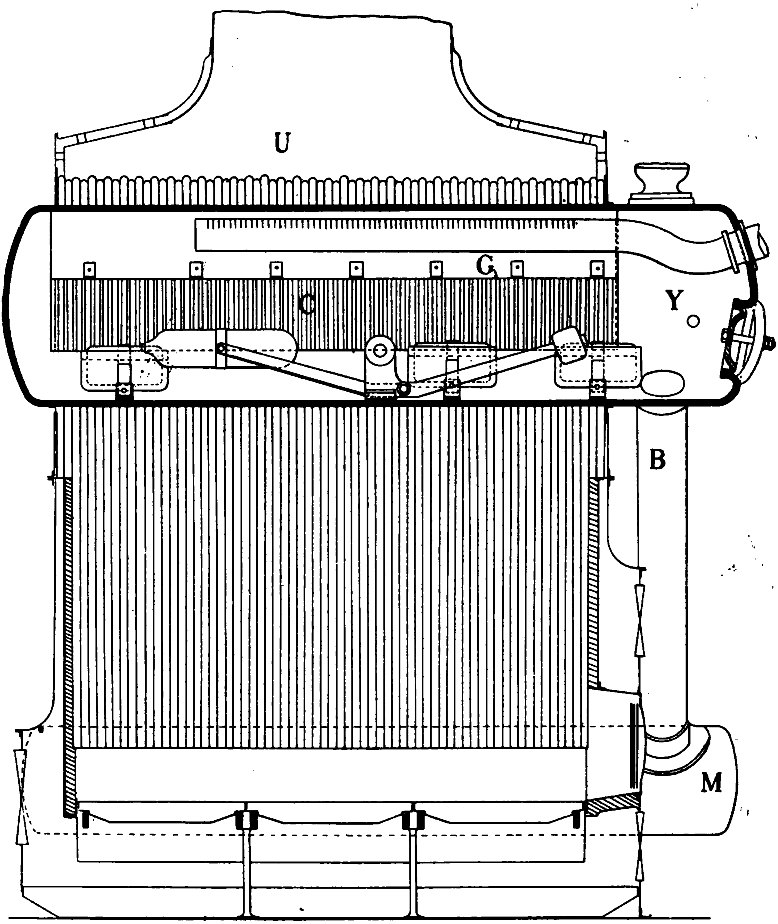


FIG. 99.

Tests have shown that, with the arrangement adopted in the Thornycroft boiler, of tubes discharging above the water level and separate downtakes, there is a rapid circulation always in one direction,—upwards in the generating tubes and downwards in the downtakes. To break up the streams of steam and water issuing from the tubes, a baffle plate G is fitted. This consists of gratings

which are secured near the center of the drum, and through which the steam and water must pass before entering Y. The feed water is discharged near the middle of Y by the automatic regulator previously described, and shown in Fig. 16. The pressure in the feed pipe should be maintained at from 40 to 50 pounds per square inch above that in the boiler. Owing to the curvature of the tubes, these are hard to clean inside and no examination is possible. As the curved tops of many of the generating tubes rise above the drum, these tubes cannot be completely filled with water

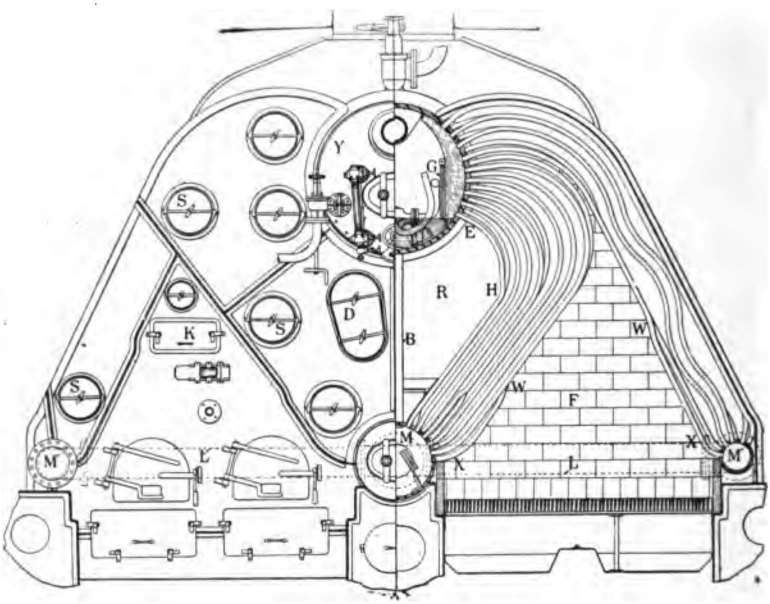


FIG. 100.

when the boilers are laid up or not in use, and these tops are, therefore, especially subject to corrosion.

"Daring" Type.—This is a modification of the "Speedy" type, necessitated by the demand for a greater power in a given space in torpedo boat destroyers, and embodies certain improvements which experience showed to be advisable. This type, Figs. 100 and 101, is fitted on the "Bainbridge," "Paul Jones," "Truxton," and "Hopkins" classes of destroyers, and to high-powered torpedo boats, like the "Farragut" and "Stringham." Fig. 100 shows a front elevation, half in section, and Fig. 101 a side elevation of the same, but to a larger scale.

The large steam drum Y is retained, but the two water cylinders are replaced by one central drum M, into the top of which most of the generating tubes are expanded. In addition to M, there is a smaller water cylinder M′, on each side, connected to Y by a few rows of tubes, which serve chiefly as insulating walls or sides of the boiler. There are two furnaces, one on each side of M, the grates of which can be made longer than before, because the large outside downtakes are replaced by a series of smaller ones B, B,

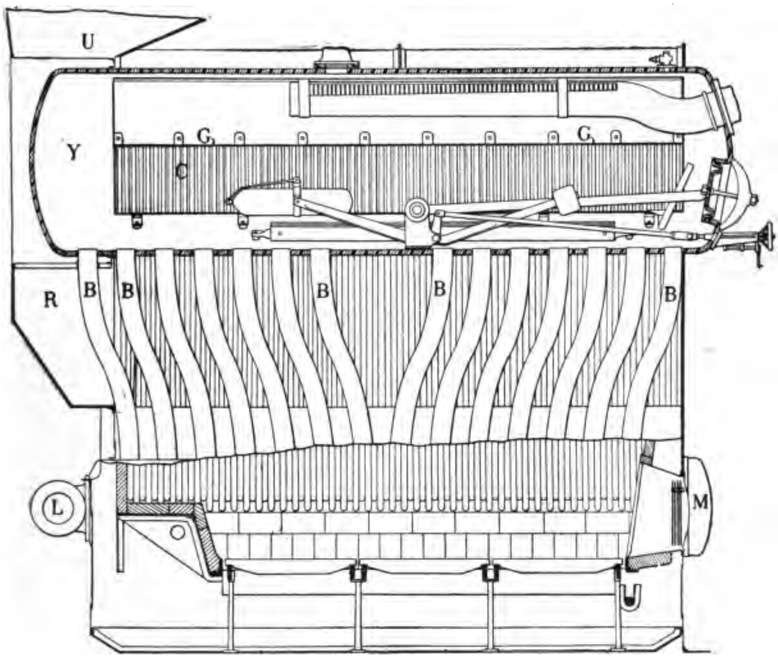


FIG. 101.

inside of the boiler casing. As the furnaces are higher, a longer length of grate can be coaled efficiently.

The circulation in the heart-shaped part of the boiler is from the bottom of Y down through B, B, into M, and up through the tubes into Y. As the tubes from the wing cylinders M′, M′, also generate steam, provision for circulation is made by connecting M to M′ by the horizontal branch pipes L at the back. The two outer rows of tubes from M′ touch each other and thus form the outer wall or boundary of the boiler. The two rows of tubes next

to the fire in each nest, form a closed wall, except for the openings below at WX, as in the "Speedy" type. Similarly, a wall of tubes is formed on each side of the heart-shaped opening R, the openings EH being left at the top. Sometimes, in very large boilers of this type, another tube wall is formed of the two rows in the middle of each central nest, as shown in the figure. This wall is intended to force part of the gases upwards from the bottom of the rows of tubes between R and this wall, and so prevent short-circuiting.

The gases of combustion from the furnace enter the openings WX, and rise between the walls of tubes to the openings at EH, through which they pass into the connection R. This space extends along the drum and ends in the uptake U at the back of the boiler. In the "Paul Jones" class of destroyers, on which the inner walls of tubes were not quite closed at the top, the contractors, the Union Iron Works of San Francisco, found difficulty in maintaining the steam pressure on the preliminary trials, and they then fitted a fire brick arch at the apex of the tubes in each furnace, in order to check the escape of the gases. Subsequent trials showed a material improvement in the steaming capacity of the boilers. The automatic stop valves on each boiler were removed, owing to unsatisfactory action during the first trials, but were replaced after the trials.

With the arrangement of tubes in this type, a much larger combustion chamber is secured, and, therefore, more nearly perfect combustion. With the inside downtakes, a more compact boiler is obtained, and more grate surface can be put in a given boiler space. The generating tubes vary from 1⅛ to 1¼ inches in diameter, the "Stringham's" boilers being the only ones which have 1-inch and 1¼-inch tubes. The downtakes are from twelve to fourteen in number and 4 or 4½ inches in diameter.

"*Ohio*" *Type.*—On the "Missouri," "Ohio," and "Arkansas," a combination of the two preceding types has been installed, which is here called the "Ohio" type, and shown in Plates XI and XII. Plate XIII is a reproduction of a photograph of this boiler, without its casing, and Plate XIV, the same boiler complete, and fitted with the Howden forced draft system, as on the "Ohio."

The wing cylinders are of the same size as the central water cylinder, and are fitted with a large number of generating tubes. The downtakes B and C, C, are outside of the casing. There are

two lofty furnaces, the sides and tops of which are formed by the wall in each nest of tubes. The gases of combustion from the furnace enter the openings at the bottom on each side, rise between the inner and outer walls of each nest, and pass through openings at the top into the uptake U directly above the tubes. The heart-shaped space R is, therefore, not used as a connection for the gases. The openings in the front of the casing, when the closed fire room system of draft is used, as in Plates XI and XII, are the same as before. They consist of non-return air doors K, K, by which the supply of air above the grates can be regulated; sight doors S, S, for the examination and sweeping of the tubes; and soot doors D, D, for the cleaning of the heart-shaped space R. The generating tubes vary from 1¼ to 1⅜ inches in diameter, and as in the previous types, discharge the water and steam into the drum Y above the water line.

DETAILS OF CONSTRUCTION.[1]

The example which has been selected is the "Daring" type, as it presents more of the important points which must be observed in the construction of the Thornycroft boiler. Variations from this example, such as the fitting of the external downtake pipes in the "Ohio" type, need no special description.

Steam and Water Drums.—These are of steel and are built according to the standard specifications. The flanged and curved heads are pressed into shape by an hydraulic press; they are made thick enough to allow for the machining where the various fittings are to be attached, so that the flanges of these can be secured to a true flat surface. The relative sizes of the drums may be gathered from the diameters usual in several of our destroyers,—steam drum, 37 inches, lower central drum, 18 to 19 inches, and wing drums, 6½ to 7½ inches.

The generating tube holes are staggered, as shown in Fig. 102. They are drilled truly radial and reamed out accurately to gage, the burrs being then taken off by means of a tool formed out of the tang end of an old file. This tool, Fig. 103, I, is run around the hole two or three times and takes the burrs off the inside and outside simultaneously. The holes for the downtakes are similarly drilled and treated.

[1] The cuts and most of the data are from Mr. John Platt's paper in the Journal of the A. S. N. E., Vol. XII.

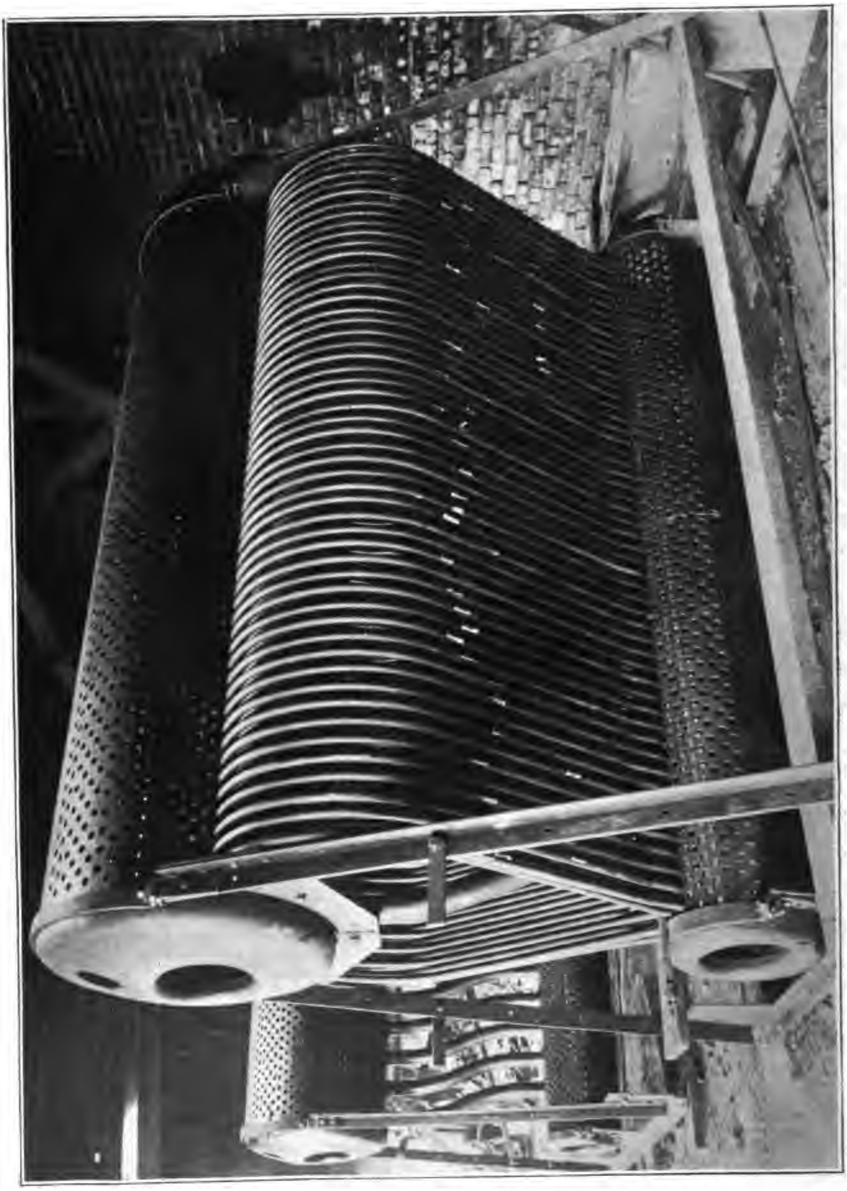


FIG. 102.

The heads having been riveted on, tube holes drilled, and the four drums finished otherwise, the upper and lower central drums are fixed in their correct relative positions on a roughly constructed frame, Fig. 103, II, ready to receive the downtakes. The lower drum rests on blocks, and the upper one on the distance pieces shown. If the drums are not truly cylindrical, they will not lie evenly on the distance pieces, and they must be trued up. Great care must be taken to have the distance between the centers of the drums absolutely correct. The shores A, A, are bolted at their upper ends to the top drum through the tube holes; their bottom ends are adjusted along the timbers C, until the centers of both barrels are plumbed in the same line, when they are spiked down. Other shores may be placed at B and B, if necessary to steadiness. The top drum is held in position longitudinally by cross braces D, D. It is important to have this framing firm and steady, as considerable force is often required to get the downtakes into place.

Laying-Out Downtakes.—These are seamless drawn, curved, steel tubes, from 4 to 4½ inches in external diameter, and connect the bottom of the upper drum to the top of the lower one. A sheet-iron template, Fig. 103, III, is made of the same outline as the downtakes, but somewhat longer. It is placed in corresponding holes in the two barrels, and the lengths of the downtakes scribed upon it, an allowance of ¼ inch, measured at the sides of the holes, see Fig 103, IV, being added at each end. The length is scribed for each pair of holes, as variations may sometimes occur, and then transferred to the downtakes, which have already been bent. The ends of these tubes are now cut off by a band saw, burrs filed off, and the openings tested to see if an expander will enter freely. Before inserting the tubes, their ends and the tube holes should be cleaned with turpentine.

Expanding Downtakes.—Commencing with the front end downtake, the top end is put into its hole in the upper drum, with the tube in the position shown by Fig. 103, V, and then tapped with a mallet until about one inch projects on the inside. It is now given a quarter turn, bringing its lower end over the corresponding hole in the lower drum, and then driven down, by a mallet applied at its upper end, until about ¼ inch projects inside. This process is repeated with the others in succession, the back end downtake being placed in position last.

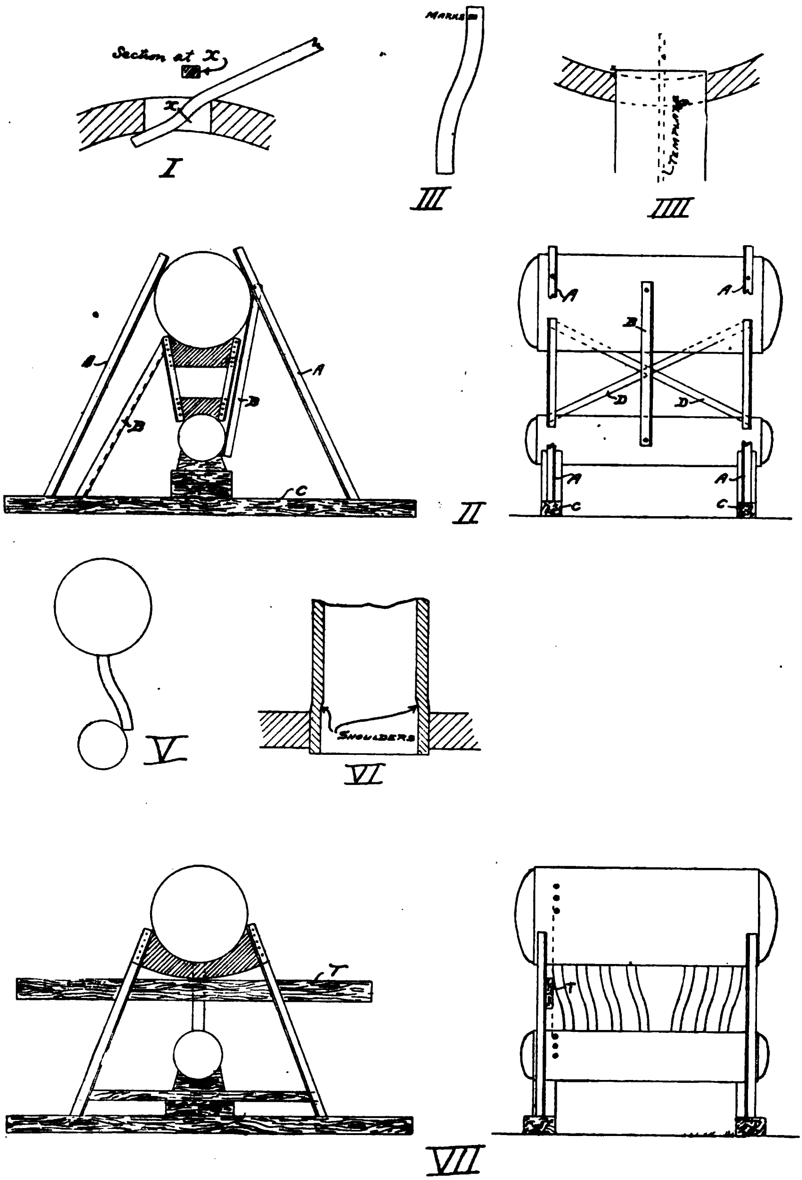

Section at X
X
I
MARKS
III
TEMPLATE
IIII
A
B
A
B
C
II
A
A
B
D
D
A
C
A
C
V
SHOULDERS
VI
T
T
VII

FIG. 103.

The alignment and position of the drums are now examined and corrected, if necessary, and then the downtakes are expanded, beginning with the front and ending with the back end one. A line should be scribed on each downtake, just outside the drum plate, and carefully watched during expanding, so that any movement of the tube in its hole may be promptly corrected by means of a mallet, before the expanding has proceeded too far. Both ends of a downtake may be expanded at the same time. Great care must be used to prevent over-expanding, as this will render the tubes brittle. Until experience has been gained, it is safe to stop expanding when a shoulder can just be felt inside the tube, see Fig. 103, VI.

Fixing and Expanding Generating Tubes.—When all downtakes have been expanded, the distance pieces are removed, and a new frame work, Fig. 103, VII, substituted. The timber T is adjusted, so that the inside face is square with the center lines of the drums, and flush with a line tangent to the outsides of the end tube holes. The generating tubes, after they are bent, are cut to the correct length and all burrs removed. They are then tested, sometimes galvanized on the outside, and the ends trued with inside and outside reamers.

Commencing with the front end tubes of the inner or A row, Fig. 104, VIIA, the bottom ends are entered first, using a mallet, and leaving a projection of $\frac{1}{4}$ inch on the inside of the lower drum. The top ends are inserted next, leaving the same projection in the upper drum, and then the sides of the tubes are brought into contact with the timber T. To get a tube into the holes, it must be sprung a little. Next, a tube in B row is put in place and then, alternately, A and B tubes, until the wall of tubes is finished by the back end tubes. Great care must be used to enter each tube into its proper hole, for, if this is not done, there will be no hole left for one end of the last tube, and all of them must then be taken out and replaced properly. The tubes for one wall may be put in place before beginning on the other one, or, both walls may be put in at the same time.

After all of the A and B tubes on both sides are in place, the two rows on each side are clamped together by angle bars E, F, Fig. 104, VIIA, set up by bolts at each end. If the boiler is long, an extra bolt is put through the middle of the angle bars to prevent springing, one of the tubes being left out for this purpose.

The tubes are now expanded, beginning at the front end and taking the A and B tubes alternately, the clamps helping to keep them in position. The precautions against the moving of tubes in their holes and over-expanding are similar to those taken with the downtakes. When all tubes have been expanded, the clamps are removed, and the omitted tubes in the middle, if any, put in and expanded.

The remainder of the generating tubes, except those forming the walls on the furnace side, are then put in and expanded, but taking only one row at a time. It will be remembered that these tubes do not touch each other; this is shown by Fig. 102, in which the first row of these tubes is in place. To preserve the proper vertical spacing in each row, pieces of wood packing, of a thickness equal to the designed space, are put between the tubes, in about the position shown in Fig. 104, VIIA. To prevent a large accumulated error, due to possible inaccurate spacing of the 27 or 28 holes in each row of a large boiler, about every tenth tube should be squared with the drums. The tubes at the back ends must be square, in order that the casing and uptake may fit properly. Owing to the close spacing of the tubes, which, for the $1\frac{3}{8}$-inch tubes of the "Ohio's" boilers, is only $2\frac{2}{3}\frac{5}{2}$ inches from center to center, along the drum, and $1\frac{1}{2}$ inches between the rows, it is sometimes difficult to get a good hold for springing them into place. The purchase, Fig. 104, X, consisting of a strap and a small bar, using one of the tube holes as a fulcrum, will then be found useful.

The last two rows, which form the side walls of the furnace, are treated similarly to rows A and B, except that the arrangement, shown in Fig. 104, VIIB, replaces the angle iron clamps, as these cannot be used. The strip of wood J is placed between the tube wall H and the row G, another strip being placed on the outside and shored against J, thus clamping the tubes between them.

Wing Cylinders.—These are now placed in their correct positions, one on each side of the lower drum. The distance between centers is maintained by the clips K, K′, K″, and the struts L, L′, Fig. 104, VIII. The centers and axes of these cylinders are leveled with those of the lower drum by means of wedges.

Expanding Generating Tubes in Wing Cylinders.—The placing and expanding of these tubes should proceed on the same lines

as for the lower drum, the following exceptions being noted. For the furnace wall of tubes, Fig. 104, VIIIA, angle bar clamps are

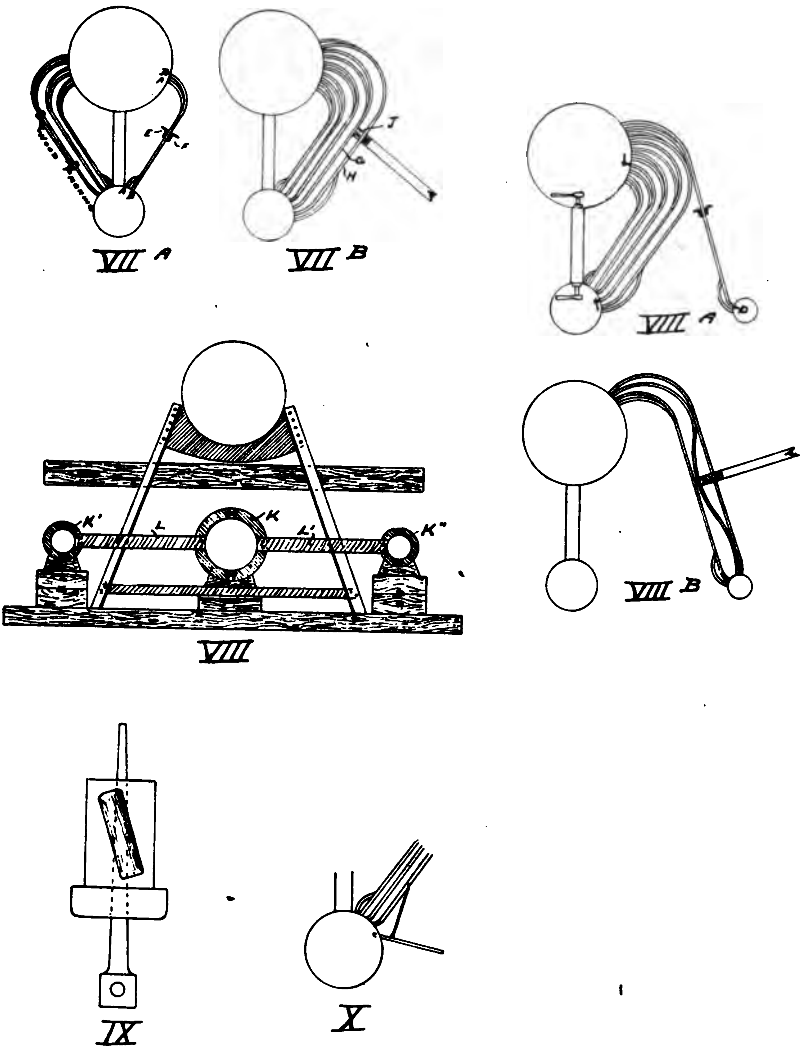


FIG. 104.

used, as in the case of the A and B tubes described above, but, for the outer wall, wood strips and shores may be necessary, Fig. 104, VIIIB. As the wing cylinders are very small, the expanding

cannot be watched from the inside, and the two rows forming the outer wall are, therefore, not put in and expanded together, as before. All tubes of the inner row are placed and expanded first, and then each tube of the outer row expanded as it is put in place. In this way, there will always be a sight hole next to the tube which is being expanded.

Tube Expander.—A slightly modified form of the ordinary Dudgeon expander is used. The mandrel or pin is tapered as usual. The rollers are tapered sufficiently to cause the expander to leave a cylindrical hole, and their axes are set at an angle of about $1\frac{3}{4}$ degrees, so as to feed the mandrel forward automatically when rotating the expander. Fig. 104, IX, shows this angle exaggerated. A stop on the expander ensures the same amount of expanding for each tube.

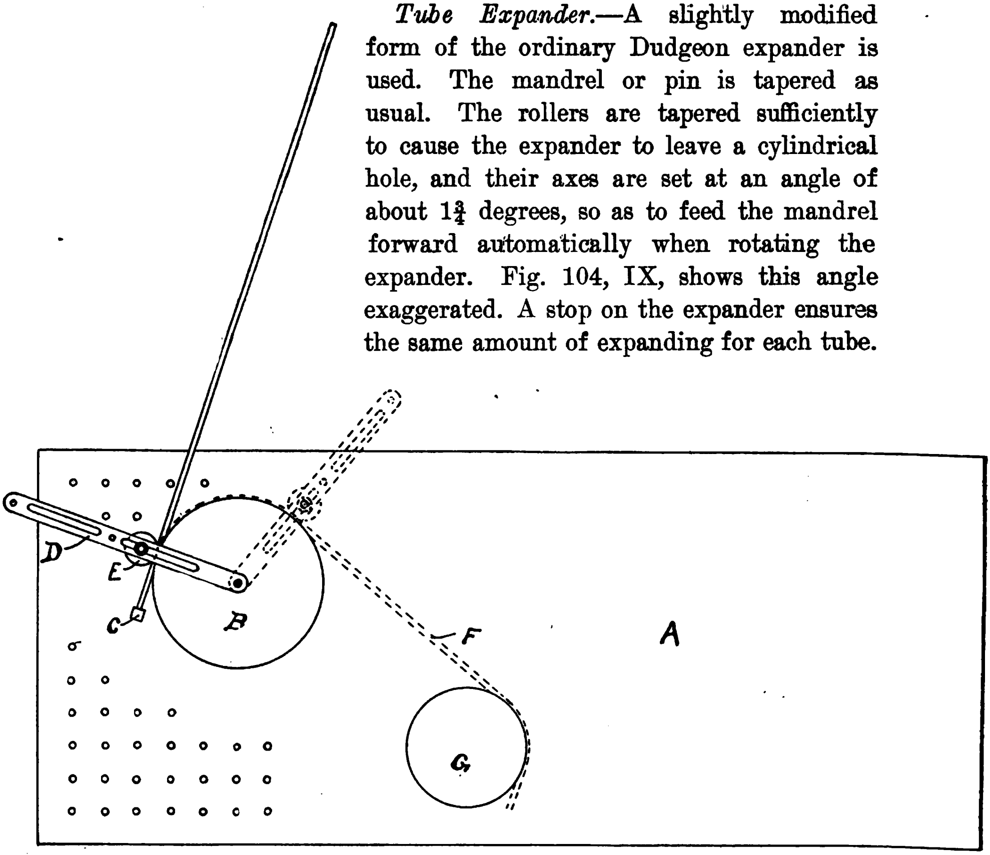


FIG. 105.

For the smaller drums and cylinders, the expander is rotated from the outside by a rope or chain drive.

Bending Tubes.—Where tubes for one boiler only are to be bent, it can be done efficiently by the following method, adopted by Messrs. W. D. Forbes & Co., who have built several bent-tube boilers for our navy. In Fig. 105, A is a bending table, filled

with slots or holes for bolting down the various formers. These are made of cast-iron, circular in form and of different radii to suit the curves desired for the upper and lower ends of the tubes. The larger former B is bolted in position and the tube to be bent is placed against it, the tube end being held by a plug C. The arm D, fitted with an adjustable roller E, is swung into place, and, by means of a lever, is rotated until the tube is bent to the desired position F. A second former G is then placed as required to give the curve at the other end of the tube, the roller arm being used as before. When the curves are of large radii, wooden formers are used. A rod with one end rounded, so as not to injure the inside, is placed in the tube, the projecting end being long enough to use as a lever. The tube is then pulled around the wooden former, the rod being withdrawn gradually as the bend is made. A system of trial and error has to be used to find the correct position of the formers to allow for the spring of the tubes. Where the bending of tubes is to be done on a large scale, it is more economical to use a special machine.

Cleaning the Boiler.—The outsides of the tubes can be cleaned by the steam or air jet through the sight holes. Soot and ashes that have accumulated on the tops of the lower drums during a run must be removed with smaller brushes. The pockets at the outsides of the lower ends of the tubes in the "Speedy" boiler should also be cleaned out. It is very necessary that the outsides of the tubes and drums, especially the latter, be kept dry.

The inside surfaces of the tube, cannot, of course, be examined, owing to the small diameter and the bends. In the "Daring" and "Ohio" types of boilers, a steel wire brush can be drawn through the tubes readily by a steel wire, owing to the easy bends, if there is no great accumulation of grease, dirt, or scale. This brushing does not, however, prove that the tubes are entirely clean, and as their number is large, and the diameters of the drums comparatively small, the process is long and inconvenient. For the occasional cleaning of the tubes, kerosene has been tried. After the fires are out, a small quantity of kerosene is pumped into the nearly full boiler. After a short time, the boiler is blown down or pumped out slowly, to allow the layer of kerosene to attack and carry along any grease that may be on the interior surfaces.

In the German navy, the interiors of the tubes of all boilers

are cleaned once a year with brushes and steel scrapers, and specimen tubes are taken out, cut up, and examined for thickness and corrosion. This cleaning, for a torpedo boat boiler, with from 900 to 1000 tubes, requires the services of one petty officer and five helpers for about 25 working days of 8 hours.

Leaky Tubes.—If the expanding has been done properly, there will be few, if any, leaky tube ends in this boiler, as the curves of the tubes will permit much expansion and contraction. The tubes may, however, corrode or burst and cause leaks. Whatever the cause, it is evident that fires must be hauled, the boiler blown down, and the steam drum and the required lower drum opened, before the leaky tube or tubes can be plugged or renewed. If the

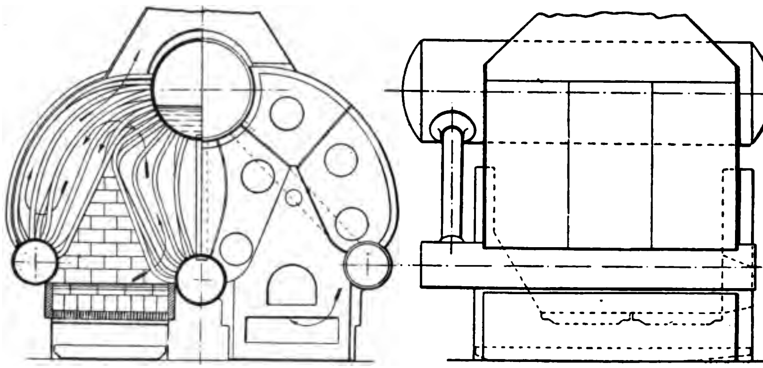


FIG. 106.

leak is in one of the inside rows, it is not always easy to locate it. Leaky inside tubes are always plugged with pine plugs, as their renewal requires the removal of several others. With the small outer water drums of the "Daring" type, the plugging of the lower ends is a difficult matter.

The remarks made above in regard to the method of cleaning and to leaky tubes, apply not only to this boiler, but, generally, to all bent, small-tube types.

Spare Parts and Tools.—In addition to the regulation allowance and spare parts, there should be several extra tubes of each shape and size used in the boiler, especially of those which form the furnace walls. One tube expander of each size, provided with a spare set of rollers and three driving pins, and several tube brushes and scrapers, with steel wire cord, should be on board.

Thornycroft-Schulz Type.—This boiler, Fig. 106, as patented by Mr. Schulz, in Germany, is a modification of the "Daring" type. It is used chiefly and extensively in the German navy.

The principal modifications are in the arrangement and curves of the generating tubes. As shown, the gases are forced to travel upwards through the center nest of tubes, down through the inside part of the outer nest, and then up through the outer and remaining part of the same nest, and thence into the uptake. The path of the gases from furnace to uptake is, therefore, longer, and better utilization of the heat of combustion should follow. Trials of two German torpedo boats of similar size, one fitted with the Thornycroft and the other with the Schulz boilers, resulted in a coal consumption of 2.2 pounds per I. H. P., at 12 knots, for the former, and 1.6 pounds for the latter. The temperature in the smoke pipes of the Thornycroft boilers was 1292°, and in that of the Schulz boilers, about 785° F. All of the tubes from the lower central drum are "drowned," i. e., discharge into the steam drum *below* the water level. The tops of the tubes from the wing cylinders are so curved that the highest point of a tube is at the discharge end, thus preventing any air pockets. Most of the wing tubes discharge above water.

Other changes consist in raising the wing cylinders above the level of the lower central drum, and in connecting them, by inclined outside downtakes, to the steam drum, instead of to the central drum by horizontal pipes. The inside downtakes, from the steam to the central drum, are retained.

CHAPTER XVII.

MOSHER BOILER.

The first type of this boiler is fitted on the "Foote" class of torpedo boats. The modified form of this type, as installed on the "Nicholson" and "O'Brien," is shown by Figs. 107, 108 and 109.

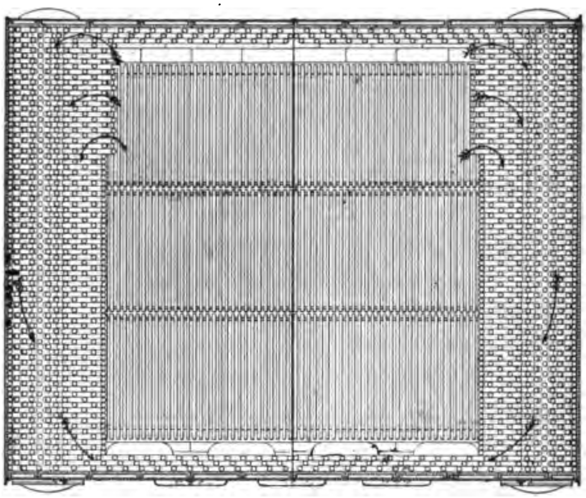


FIG. 107.

It is of the bent, small-tube type, with the discharge of all generating tubes above the water level.

There are two steam drums, each having its nest of tubes and a water drum. The two inner rows of tubes on each side, for about three-fourths the length of the furnace from the front, are bent to form a wall, the remaining tubes in these rows being open. There is only one furnace, the crown of which is formed by bringing the tube walls from each side in close contact. The back of the furnace is formed of brick work and a wall of tubes, bent low as shown. Back of this is the usual protecting wall of brick work and non-conducting material. The front of the furnace is formed of brick work. The two outer rows of tubes in each nest

form a continuous wall, and, as they enter the steam drum at the *bottom,* and are farthest removed from the direct influence of the fire and hottest gases, they act as downtakes.

In the "Foote" class, the inner walls are continuous from near the crown of the furnace to the points where they enter the steam drums. The gases, after entering among the back tubes, return to the front and rise into the uptake, which must be on the front of the boiler. In the later form, these tube walls are not continuous on top, about one-third of the tubes at the front end being left

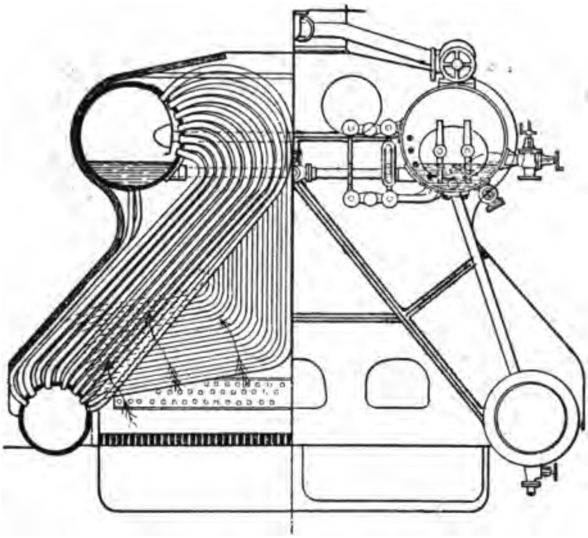


FIG. 108.

open to allow the gases to escape at the top of the boiler, as shown in Fig. 109.

The two sides of the boiler are independent of each other up to the main steam pipe, into which the branch from each steam drum is led. In case of a leaky or ruptured tube in one nest of tubes, the other half of the boiler could still be used. This would be justified only in case of an extremely great emergency, as nearly all of the tubes of the unused half would, very likely, be burned and require renewing.

The drums are of steel, the inner part, into which the tubes are expanded, being heavier than the rest of the shell. The steam drums are 24, and the lower ones, 16 inches in diameter. The tubes

are $1\frac{1}{8}$ inches in outside diameter, are staggered in the drums, and spaced one diameter apart. The number of tubes used as downtakes is about one-eighth of the whole number. All tubes are expanded and the ends trumpeted or flared out by a drift. In the later torpedo boats, the brick work in front and back is perforated, a regulating valve over these holes controlling the air supply above the grate. The closed fire room system of draft is used.

Florida Type.—This boiler is similar to the Yarrow and the Blechynden, and, as designed by Mr. Mosher and now built under his patent rights, is shown by Figs. 110 and 111, which, with a few

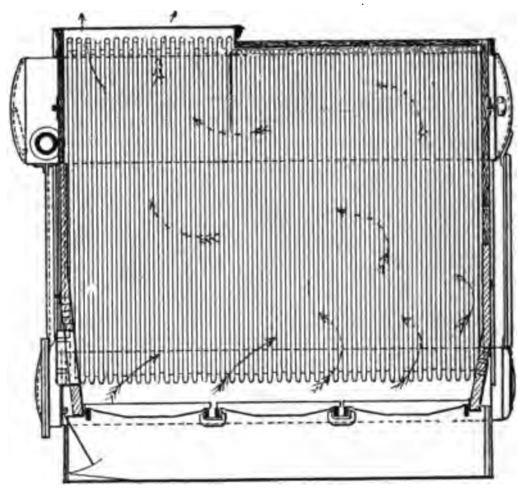


FIG. 109.

modifications, are applicable to the boilers of the monitor "Florida."

There is a cylindrical steam drum, 42 inches in internal diameter, and two water drums, the section of which is shown in Fig. 110, all three made according to the standard specifications. The parts of the drums which contain the holes for the tubes are made heavier, as usual. The lower drums are cylindrical at the bottom, the inner radius being about $9\frac{1}{2}$ inches; the tube sheet part is a curve, the crown of which, inside, is 15 inches from the lower part of the drum.

The tubes are straight in the center of each nest, and curved slightly and increasingly as they approach the outside rows. They do not enter the drums normally, and the holes in the latter must,

therefore, be drilled at an angle. The tubes are expanded and trumpeted, the ends projecting into the drums from $\frac{1}{8}$ to $\frac{1}{4}$ inch. The tubes are staggered and are all open. In order to retain sufficient strength in the part of the drums which is drilled for the tube holes, the tubes must be spaced so far apart that the area of the

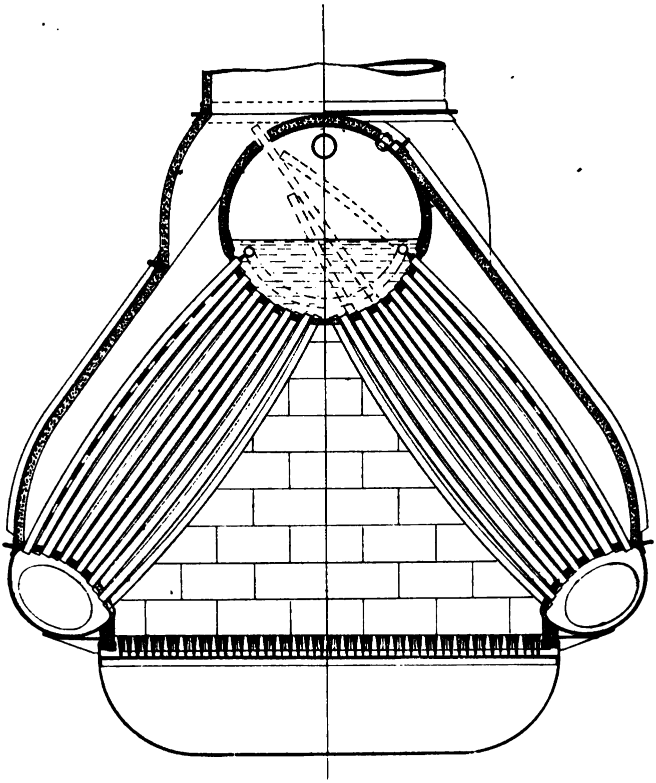


FIG. 110.

openings between them is several times too large for the proper discharge of the gases. These would, therefore, pass from the furnace around the tubes and into the uptake by the shortest way, and would thus come in contact with the upper part of the tubes only, or with about one-fourth of the heating surface. To prevent this loss of heating surface and the resultant high temperature in the smoke pipe, a perforated brick baffle plate is fitted to each outer

row of tubes, the combined area of the holes being slightly greater than that of the uptake. The gases are thus not only distributed more evenly over the entire tube surface, but are retarded in their flow to the uptake, and hence give up much more of their heat to the tubes.

A special point to be noticed is the method of forcing the circulation of the water. The internal feed pipe consists of two

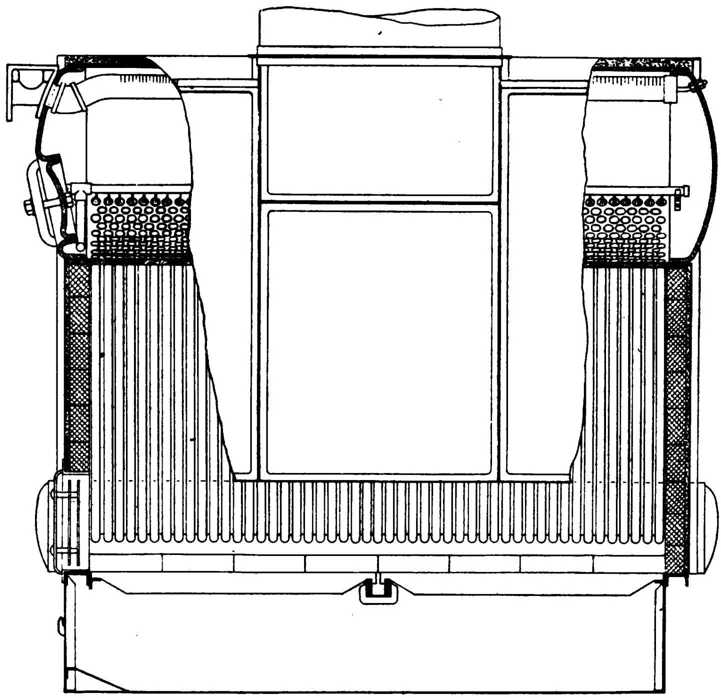


FIG. 111.

branches, one on each side, directly over the two outer rows of tubes. Each branch pipe is closed at the further end, and is perforated on the under side with two rows of $\frac{3}{16}$-inch holes, a hole being opposite each tube opening. The feed water is thus projected into each tube of the two outer rows and induces a heavy current downward. As the outer rows are furthest from the fire, the coolest feed water is, therefore, brought into contact with the coolest heating surface, and great efficiency of feed water heating thus secured.

The manner of removing and inserting a tube, through the small holes in the upper part of the drum, is easily understood from Fig. 110. These holes are closed by conical-headed plugs, see Fig. 112, set up by nuts on the outside of the drum, a grommet or washer of soft copper tubing around the head making the joint.

On the "Florida," the following modifications were made: The Bureau of Steam Engineering required, in addition to the above method of circulation, two outside downtakes, each $8\frac{1}{2}$ inches in internal diameter. The number of tubes in the outer rows of both sides is 232, or one-sixth of the whole number of tubes. The plugs for removing tubes are omitted, on account of want of room between the armored deck and the drum. The brick wall in front and back of the furnace is perforated and provided with air regulating valves. The closed ash pit system of draft is used.

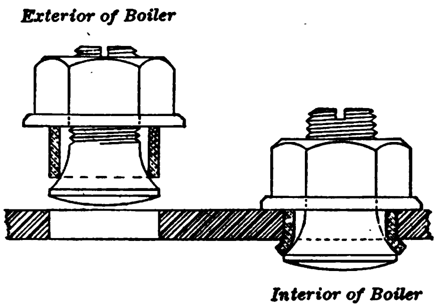


FIG. 112.

Spare parts.—For the "Florida" boilers some bent tubes of each curvature should be carried, or a lot of straight tubes, templates for each curvature being added in this case. The tubes can be easily bent, without flattening, to the required curvature over a round log.

YARROW BOILER.

This boiler, as fitted on the "Nashville," is, in general, like the Mosher boiler on the "Florida," the differences being explained below. On the "Nashville," there are four Yarrow and two single-ended shell boilers, the steam pressure in the former being 250, and in the latter, 160 pounds per square inch. All the tubes of the Yarrow boilers are straight and $1\frac{3}{8}$ inches in outside diameter. They discharge below the water level. The tubes in each nest are in nine rows and staggered. The original tubes were of copper, but were replaced by steel tubes after about a year's service.

The cylindrical steam drum, 28 inches in internal diameter, is of steel and made in halves. The two parts are held together by

steel bolts and nuts, with a joint of red lead. The flanges were planed true and grooved, and slightly beveled at short intervals for the insertion of wedges when the joint is to be broken. The lower half of the drum, containing the tube holes, is $1\frac{3}{16}$ inches thick, while the upper half is only $\frac{7}{16}$ inch thick. The water drums are of steel made in two parts, secured together as just described for the stream drum, and are shown at J, Fig. 9, 1. The lower part is cylindrical, $7\frac{1}{2}$ inches inside radius, and the upper part, or tube sheet, is flat. In the bottom of each water drum are five handholes, and one at each end.

The Thornycroft feed regulator is fitted to these boilers, the feed being independent of that for the shell boilers. The ash pit system of draft is used, as shown in Figs. 9, 1 and 9, 2. On the contract trial, with an air pressure of $1\frac{1}{4}$ inches, the fires were fed regularly every 8 or 10 minutes, and the fires were kept from 10 to 14 inches thick.

Leaky Tubes.—The lower ends can be plugged through the handholes in the water drums, and the upper ends from the steam drum. If a tube is to be renewed, the tubes in front of it must be cut out. The new tubes can then be put in place by stepping them from one hole to the other. The upper ends can be expanded easily. The lower ends can be expanded by an angular expander, as explained under the Thornycroft boiler, or, if near a handhole, by the ordinary expander.

Later Types.—In the later types of this boiler built for European warships some changes have been made.

The steam and water drums are made in one piece, the ends being either welded or riveted. The tubes are of steel, the two rows next to the fire being $1\frac{3}{8}$, and the others, $1\frac{1}{8}$ inches in external diameter; the latter are straight, and the $1\frac{3}{8}$-inch tubes curved slightly. The reason for the adoption of this curvature is that these front rows, which are subject to higher temperatures and more sudden changes than the rest of the tube surface, have in some cases, when initially straight, shown a tendency to spring against each other in varying directions. This obstructs the uniform flow of the gases, besides being mechanically objectionable. By slightly curving the outer rows, any springing takes place in a known and definite direction, and does not, therefore, have this effect. As the curvature is slight, it does not appreciably interfere with cleaning or inspection.

Straight large tubes are fitted externally to act as stays and downtakes. In addition to these, a certain number of generating tubes at each end of each nest is baffled off from the fire, so that these tubes will also act as downtakes. Instead of a continuous row of tubes on the fire side, several gaps are made by omitting about one-half of the tubes in an athwartship row. The object of this is to throw a greater number of tubes into actual contact with the fire, and thus somewhat relieve the outer rows, which are very severely worked. This arrangement also somewhat increases the combustion space. The feed water flows by gravity from the feed tanks through the filters to the feed pumps. The tubes of boilers built by Messrs. Yarrow & Co. are always galvanized on the inside, as well as on the outside.

NORMAND BOILER

This boiler is fitted on the torpedo boats of the "Craven," "Bagley" and "Blakely" classes, and, in a slightly changed form, on the "Porter" and "Gwin" classes and the "Morris." It has small curved tubes which discharge below the water level. Fig. 113 shows a front elevation, half in section, of this boiler, as fitted on the "Bagley" class. There is a large steam drum, two smaller water drums, two outside downtakes at the back, and two nests of generating tubes, making the boiler somewhat similar to the Thornycroft of the "Speedy" type.

The shell of the steam drum, 35.43 inches in internal diameter, is made of two plates, lapped and riveted, the upper half being .51 inch, and the lower one, which is drilled for the tube holes, .94 inch thick. The heads are dished and riveted to the shell. A steam dome is riveted and braced to the drum, as shown. The shells of the water drums, 15.74 inches in internal diameter, are made of two steel plates welded together, the upper or tube plate being .67 inch, and the lower one, .35 inch thick. The front heads are dished and bolted to flanges on the shell. The back ends are of pressed steel, with nozzles for the downtakes and are lapped and riveted to the shell. The two drums are held securely in position by an athwartship brace at the front and back ends. The front end of the steam drum is supported by a hollow brace from each lower drum. The interior of each brace communicates

through holes in the shells with the water in the drums, and the braces thus serve, in a measure, as circulating tubes.

The generating tubes, $1\frac{3}{16}$ inches in outside diameter, are curved for the greatest part of their length, and enter the drums

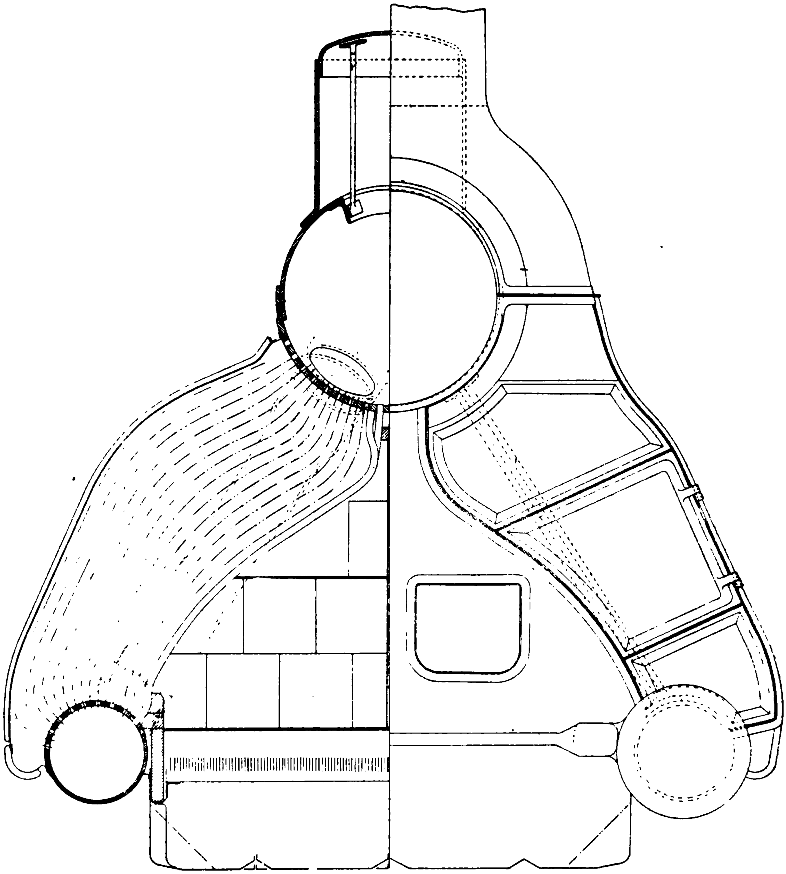


FIG. 113.

normally. The tubes forming the sides of the furnace do not meet in the middle at the top, as in the Thornycroft boiler. This small space is filled in with fire brick to protect the steam drum from the gases, and to close the small openings left between the upper ends of the two inner rows of tubes. The front and back of the furnace are built of brick.

Each side of the furnace, for about two-thirds of its length from the front, is formed of a wall of tubes; in the remaining one-third, the tubes are open and permit the gases to pass between them. The sides of the grate are brick walls, which not only protect the lower drums and lower ends of these tubes, but also close the small spaces at the bottom of the tube wall. The two outer rows of tubes in each nest are bent to form a wall, which is complete, except at the upper part for about one-third the length from the front. The rest of the generating tubes are staggered. By this arrangement, the products of combustion are forced to enter between the open-spaced tubes at the back. They then *return* between the tubes and rise, through the open spaces left in the outer wall, into the uptake at the front end of the boiler.

The circulation of the water is from the steam drum through the downtakes into the lower drums, and thence upwards through the generating tubes, the discharge being into the steam space. The dome gives opportunity for the separation of the water from the steam as the latter rises, but increases the height of the boiler. Each boiler is supplied by its own feed pump, and no feed regulator is fitted. The grates are very long, 9 feet $6\frac{1}{4}$ inches. They are the longest in the navy, and are the same for the five boats of the "Bagley" and "Craven" classes.

In the smaller and less powerful boilers on the "Blakely" and "De Long," the grates are reduced to 7 feet 9 inches in length, and the generating tubes are $1\frac{1}{8}$ inches in outside diameter. Thirteen tubes are left open at the back of the inner wall on each side and eleven at the top of the outer rows. The Thornycroft feed regulator is fitted to each boiler, and the steam dome is omitted. The tubes have a slightly different curvature, and those forming the inner walls are bent to meet at the top. An automatic stop valve, designed and made by the contractors, the Geo. Lawley & Sons Corporation, is fitted to each boiler and worked satisfactorily on the trials.

Morris Type.—In this type, the tubes are straight for a greater part of their length, being bent at the upper and lower ends, as shown in Fig. 114. There is no steam dome. The heads in the steam drum are of cast steel and are riveted to the shell, which is made as before. The generating tubes, $1\frac{1}{8}$ inch in outside diameter, are very thin, No. 15 B. W. G. The inner and outer tube walls are built as before, except that the number of tubes left open

at the bottom and top is smaller in proportion, being about one-sixth only. A simple feed water regulator with a ball float is fitted to the drum.

The brick lining at the front and back of the boiler, in the com-

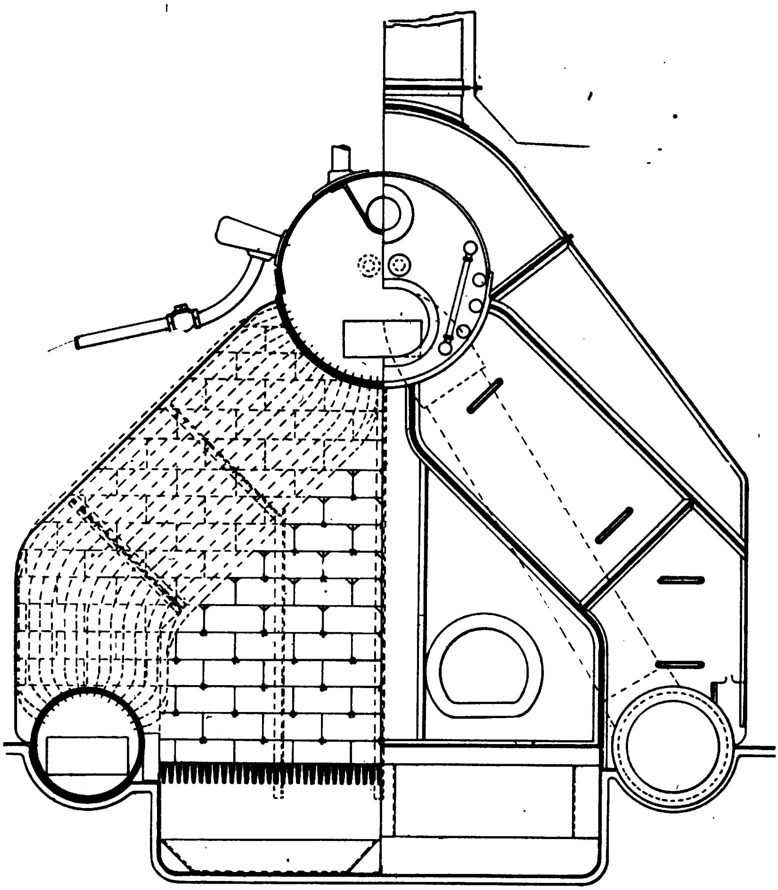


FIG. 114.

bustion chamber space of the furnace, has triangular holes in it for the admission of air from the spaces formed between the brick wall and the casing. These spaces communicate with the ash pit, through which all the air for combustion is admitted from the closed fire room. This arrangement is the same as in Normand's original boiler, and serves to heat the air before it enters the com-

bustion chamber and to prevent excessive heating of the outside casing. The bricks are secured to the casings by flat-headed bolts.

FORE RIVER BOILER.

This is a bent, small-tube boiler, Plates XV and XVI, made by the Fore River Ship and Engine Co., and is fitted on the torpedo boat destroyers "Lawrence" and "Macdonough." It has drowned tubes, and the general features are similar to the "Normand" type, with a modification designed to make two furnaces. The drum is of steel, 42 inches in internal diameter, with welded joints, and the lower part heavier than the rest; the heads are welded on. There are two wing drums and a central one, all in the same plane and of the same size, 18 inches in internal diameter. Most of the generating tubes, $1\frac{1}{8}$ inches in external diameter, run from the

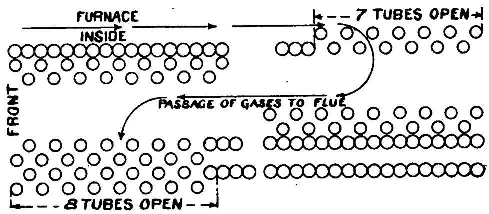


Fig. 115.

steam to the wing drums, a few rows running to the central drum, and separating the furnace space into two parts.

The back and front of the boiler are made of brick walls, the latter being pierced by triangular air holes opposite the furnace ends. The outside casing is separated from the walls by an air space at each end, $1\frac{3}{4}$ inches wide, which communicates with the ash pits, through which all air enters from the closed fire room.

On the furnace side of the wing nests, the two inner rows form a wall, except at the back end, where seven tubes are left open, see Fig. 115. The two outer rows, and the next two rows from the outside, are bent to form walls, except eight tubes at the front end of each. This inside wall is designed as a shield for the outer one, so that the tubes in the latter, being of a lower temperature, will act as downtakes. With this design of tube walls, no outside downtakes were contemplated. The Bureau of Steam Engineering, however, required additional means for circulation, and a vertical

downtake, $6\frac{1}{2}$ inches in diameter, was fitted between the back ends of the steam and lower central drums, with a horizontal branch to each wing drum, the latter being shown in Plate XVI. The two inner rows of tubes on the lower central drum form a complete wall, thus closing off the diamond-shaped space from the gases of combustion; the other rows are open. All generating tubes are bent to enter the drums normally.

The feed water enters at the front of the drum, through a feed regulator, and by means of an internal pipe, is discharged into the vertical downtake at the back. The internal pipe for the auxiliary feed, on the opposite side of the drum, extends a little beyond half the length of the drum and discharges below the water level.

The path of the gases of combustion is shown by Fig. 115, the uptake being on top of the front end of the boiler. In one of the boilers of the "Lawrence," the row of tubes next to the furnace wall of one of the wing drums is omitted, a mistake having been made in spacing the holes in that drum.

Plate XV shows the casing completed, and Plate XIV, the boiler before the casing was put on, both views having been taken after the boiler was placed in the vessel. The vertical plating outside of the boiler is a coal bunker bulkhead, which meets the frames of the vessel below; the beginning of the deck plating is also shown. The lower drums rest on six vertical saddle plates which are riveted to as many frames. The construction of the ash pans and supports for bearer bars is made clear by the cuts.

The two circular flanges, which are riveted to the front of the casing, show the connection for the pipes of the fire-extinguishing apparatus. This is fitted to most tubulous boilers for the purpose of quickly putting out the fire in the furnace, when a ruptured or leaky tube renders it necessary. The pipe is fitted with a spray nozzle on the fire side, and is connected generally to the fire main of the vessel.

SEABURY BOILER.

Figs. 116 and 117 show this boiler as installed on the torpedo boat destroyers "Wilkes" and "Stewart." It is similar to the Fore River boiler, and is built by the Gas Engine and Power Co. and Chas. L. Seabury & Co. The dimensions given on the figure are for the boilers of the "Wilkes," those for the "Stewart" being larger.

The drums are of welded steel, thickened for the tube sheet part. The generating tubes are $1\frac{1}{8}$ inches in outside diameter, and are bent only in one place. They, therefore, do not enter the steam drum normally, and the holes in the latter must be drilled at an angle. As the lower drums are smaller, some of the tubes are slightly bent at the bottom in order to place them in a smaller arc.

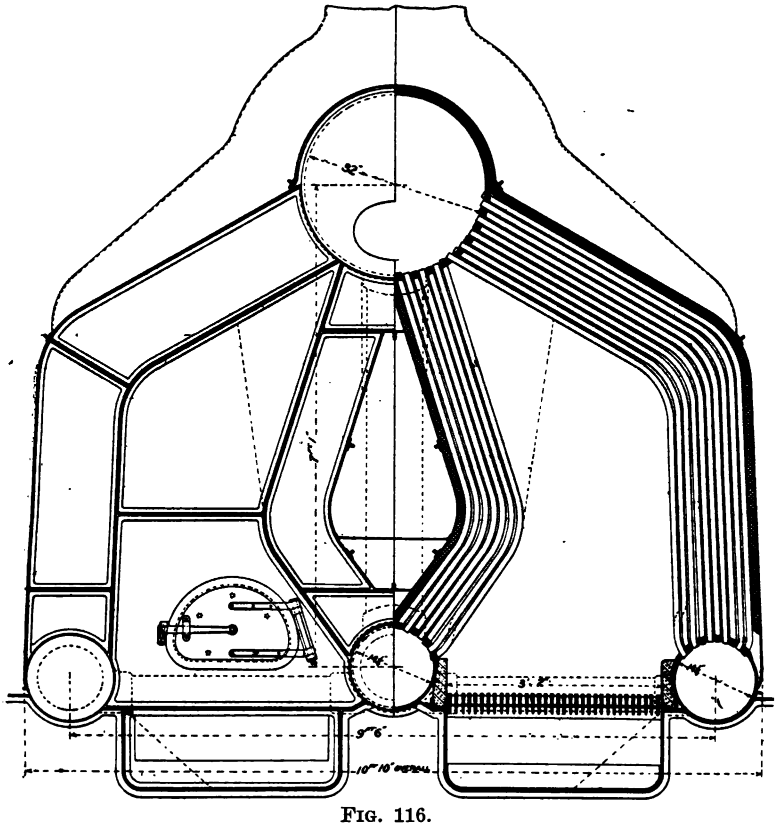


FIG. 116.

The sides and top of the furnaces are formed by the two inner rows on each side, these forming a wall except at the front end. Here eight rows are left open. The outer rows of tubes are left open and are covered with asbestos cardboard and magnesia. The front and back of the boiler are formed of $2\frac{1}{2}$-inch fire bricks, covered with two inches of magnesia. The lozenge-shaped central

opening is shut off from the tubes by asbestos and magnesia. The gases of combustion must pass to the front, where they enter among the open tubes, and then return between the tubes, passing thence

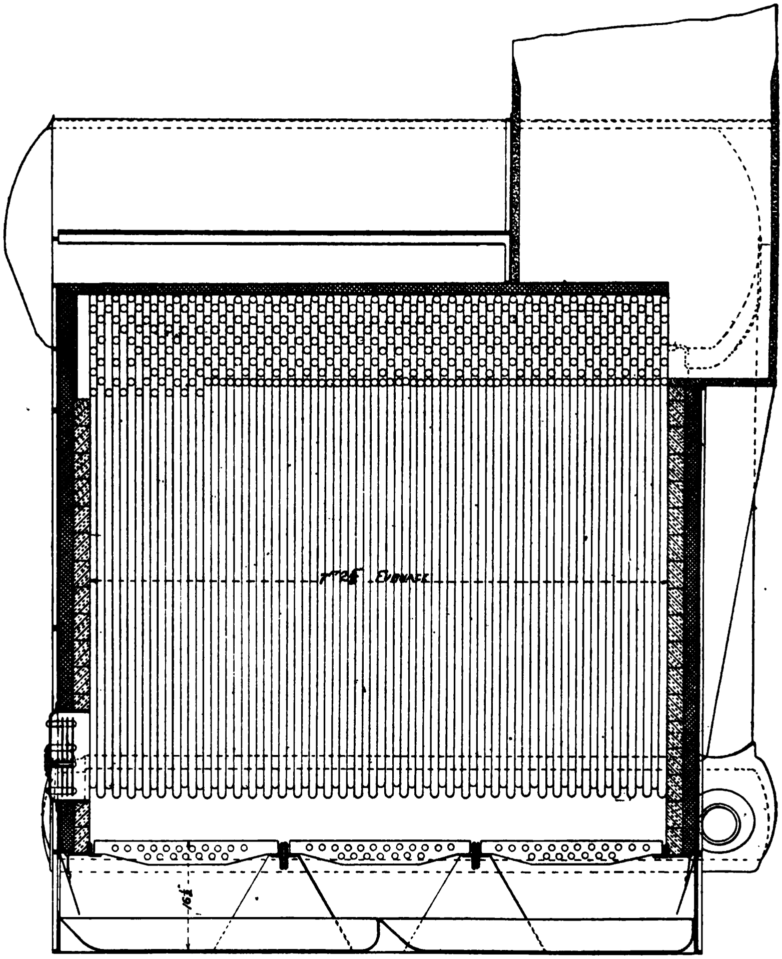


FIG. 117.

into the uptake at the back. The uptake extends a little beyond the back end of the steam drum and surrounds that part of it.

There is one downtake connecting the back end of the steam drum to the middle drum. Horizontal branches connect the back ends of the middle and wing drums. The downtake for the

"Wilkes" is 9 inches, and for the "Stewart," 11 inches in diameter. The closed fire room system of draft is used, the air entering the ash pits. The working pressure in the boilers of the "Wilkes" is 250 pounds, and of the "Lawrence," 300 pounds per square inch.

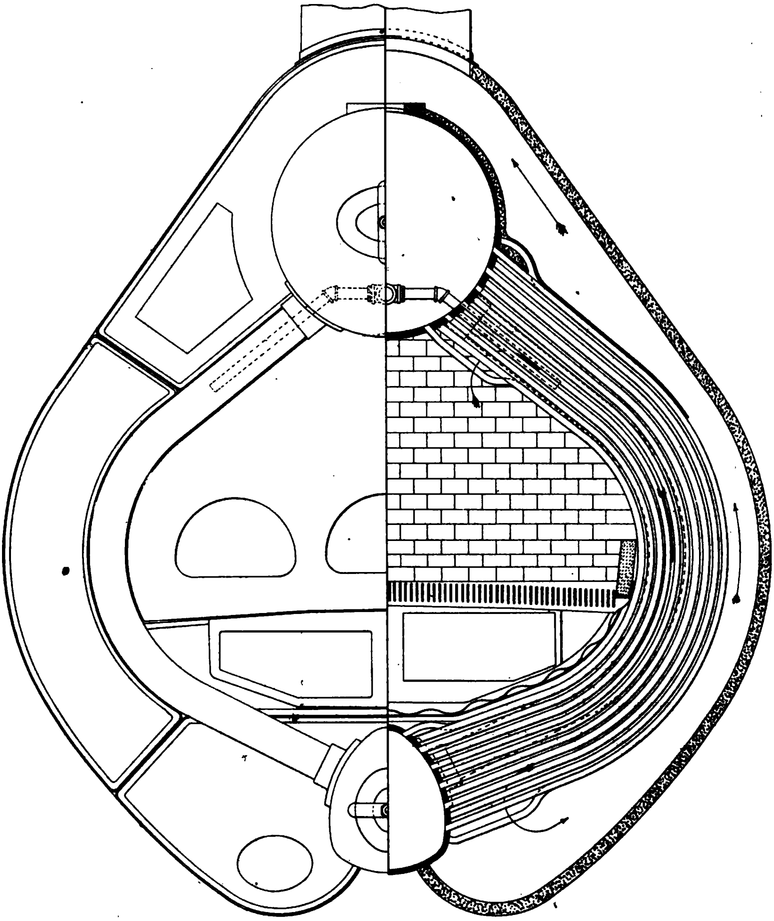


FIG. 118.

Bailey Type.—As fitted on the torpedo boat Bailey, the Seabury boiler presents an unusual construction, see Fig. 118.

The steam drum, 36 inches in diameter, is of the usual construction. The single water drum, 18 by 23½ inches, is shaped as shown and is below the ash pan, and, therefore, below the fire room

floor. There are four curved downtakes, two at each end. The generating tubes, curved for the greater part of their length, have straight ends, and, therefore, enter the drums at an angle. The two inner rows form a wall which is open at the top, and the two outer ones, a wall open at the bottom, forcing the gases of combustion to take the course shown by the arrows. The small spaces left at the top of the outer wall are closed by asbestos. The drum, inside of the casing, is protected by asbestos, and this covering extends down along the outer wall of tubes for some distanee. About three-fourths of the tubes are 1 inch, and the rest, placed at the inner and outer walls, are $1\frac{1}{8}$ inches in outside diameter.

The front and back of the single furnace are of brick. The corrugated ash pan protects the inner tubes below the grate. The grate is 9 feet long, formed of four lengths of bars, and $6\frac{1}{4}$ feet wide. The closed fire room system is used, the air entering the ash pit at the front and back. The uptake is in the middle of the length of the boiler. The feed water is discharged downwards, the end of the feed pipe being well inside of each downtake. The amount of water in this type is larger than in other tubulous boilers. Owing to the position of the water drum and the adjoining casing, these are exposed to the action of the water in the bilge, and, therefore, much more liable to corrosion.

WARD BOILER.

The type of this boiler shown by Plate XVII is fitted on the monitor "Monterey" only, there being four of these in combination with two shell boilers. This boiler is cylindrical in shape, and consists essentially of a vertical central drum, which is surrounded about the middle of its length by a number of concentric, semicircular generating tubes, slightly inclined to the horizontal, the drum and tubes being connected by a number of vertical and horizontal manifolds.

B is the central drum, its top and bottom shown in section. Radiating from it, and diametrically opposite to each other, are two rows of vertical cast steel headers F and H, which are connected to the lower horizontal manifolds C and P, also of cast steel, by the pipes E and N, respectively. These pipes are screwed into the headers, and secured in the lower manifolds by stuffing boxes, the glands of which are made in halves. The tops of the headers H

are recessed for stuffing boxes, into which lipped projections on the under side of the upper horizontal manifold I are secured by glands made in halves, as shown in the enlarged section to the left of the drum. The headers F are closed at the top by screw plugs and do not rise as high as H. The three horizontal manifolds are connected to the central drum at their inner ends, C and P rigidly, and I by a stuffing box and gland.

The semicircular generating tubes G, $1\frac{1}{16}$ inches in external diameter and No. 8 B. W. G. thick, are secured to the headers by steel bushings with right and left-hand threads, as shown in the enlarged section to the right of the drum. Each pair of headers, with its rows of semicircular tubes on each side, is thus independent, and, where there is room overhead, can be raised for examination or repair by disconnecting the two stuffing boxes in C and P and removing the manifold I.

An internal pipe, which enters the central drum at its base, conducts the feed water upward to about the water level in the drum. There the water is discharged against an inverted dish-shaped baffle, which deflects it downward, as shown by the arrows; on reaching the bottom of the drum, it passes into the manifolds C and P, and thence into E and N and the headers. The water from C passes upwards through the tubes G into H, from which the water and steam formed in G and the headers pass into I, and thence into the drum. The steam rises, through a perforated baffle plate R, to the dry pipe, and most of the water falls to the level in the drum.

The grate is cast iron and annular in form. The lower part of the drum, in the furnace, is protected by a brick casing from the intense heat of the fire. Doors are placed at suitable intervals around the furnace, but, owing to the location of the boilers in the corners of the fire rooms, it is rather difficult to fire through the doors nearest the bulkheads. The gases rise among the coils of tubes into the uptake on top. The closed fire room system of draft is used. The construction of this boiler makes ample provision for contraction and expansion.

In another form of this type, only one vertical header is used, the concentric coils of generating tubes being practically circles. The ends of each coil enter the header at different levels, thus inclining the coils to the horizontal, as before. Each coil is made of two tubes coupled together on the side opposite the header. By

this arrangement of a single header, the grate can be made more accessible when the boilers are put in the corners of a fire room.

Launch Type.—Nearly all of our launches are fitted with this

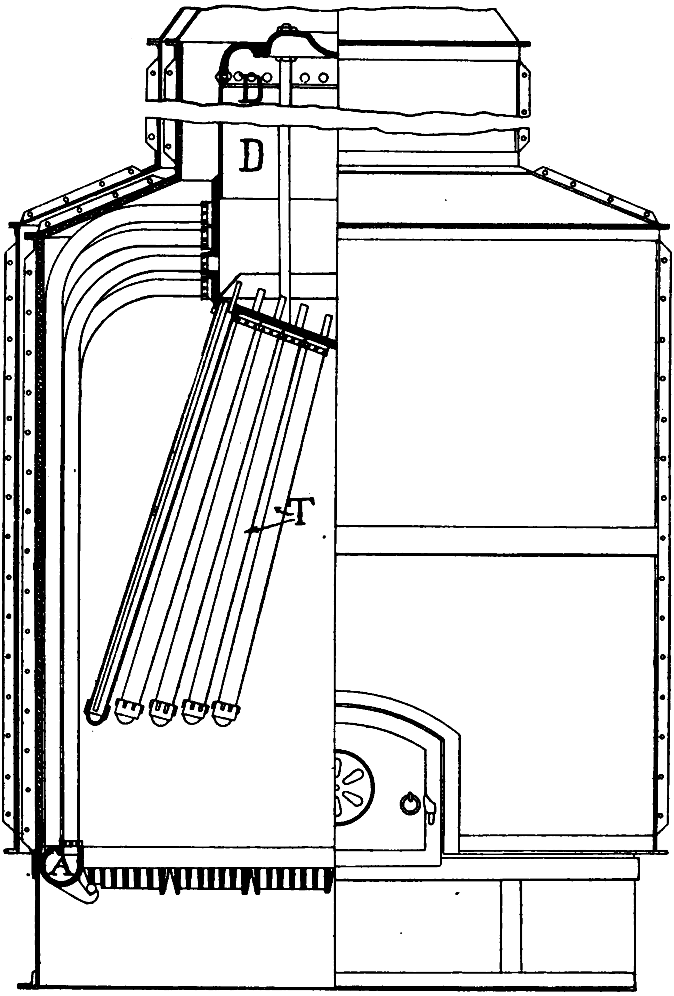


FIG. 119.

type, which is now the standard boiler for steamboats. These boilers are either cylindrical or square in shape, the arrangement of tubes and other parts being shown in Fig. 119, which is a cut of a cylindrical boiler.

A circular manifold A, of cast steel, with a hollow projection for the furnace door opening, forms the base of the boiler and supports the grate. This manifold rests on a cylindrical ash pit structure which is secured to the keelsons. On the upper surface of the manifold and its projection, there are two rows or rings of staggered holes, into which vertical tubes, 1¼ inches in inside diameter, are secured by screw couplings. These tubes are straight, except at the top, where, by an easy curve, they are bent through ninety degrees, and enter the vertical drum D, to which they are secured by screw couplings. The upper part of the drum is of plate steel and cylindrical, and the lower part of cast steel, cylindrical where the bent tubes enter it and conical below that. As the diameter of the manifold is about 2½ times that of the drum, the tubes of each row from the manifold cannot enter the drum in the same horizontal plane. Every other tube, therefore, enters below the adjacent one, necessitating four rows of holes in the drum. Some sizes of this type have only one row of vertical tubes; in this case, there are only two rows of holes in the drum.

Into the conical bottom of the drum, a number of straighgt *hanging tubes* T, of wrought iron or steel, usually 1½ inches in internal diameter, is screwed. These tubes, which are similar to the Field tubes already described, project into the cylindrical space inside of the vertical tubes and above the fire. The outer or lower end of each hanging tube is closed by a screw cap, and its inner end, by a tight-fitting plug, in which are two small holes. Into each hole is fitted a small brass tube, open at both ends, one tube extending inside of the hanging tube to within an inch of the bottom, and the other and shorter one projecting about six inches into the drum. This is shown in the section of the outer hanging tube.

Around the inside of the drum, an inclined diaphragm P is fitted below the openings of the lower row of vertical tubes. The feed water enters above this triangular trough and goes down the outer rows of tubes, where a double row is fitted, or, down part of the tubes, where there is only one row. In the doube tube boilers there is, naturally, an ascending current in the inner and hotter row of tubes; but, in single tube boilers, it has been found that some of the tubes will have ascending currents in them, while others will have the down currents of the feed, although all are exposed to the same heat. The hanging tubes, being exposed to the greatest heat, set up a rapid circulation in the water in the drum by means of the

small tubes, water entering through the internal tube, and steam and water being projected upward through the external one. Sur-

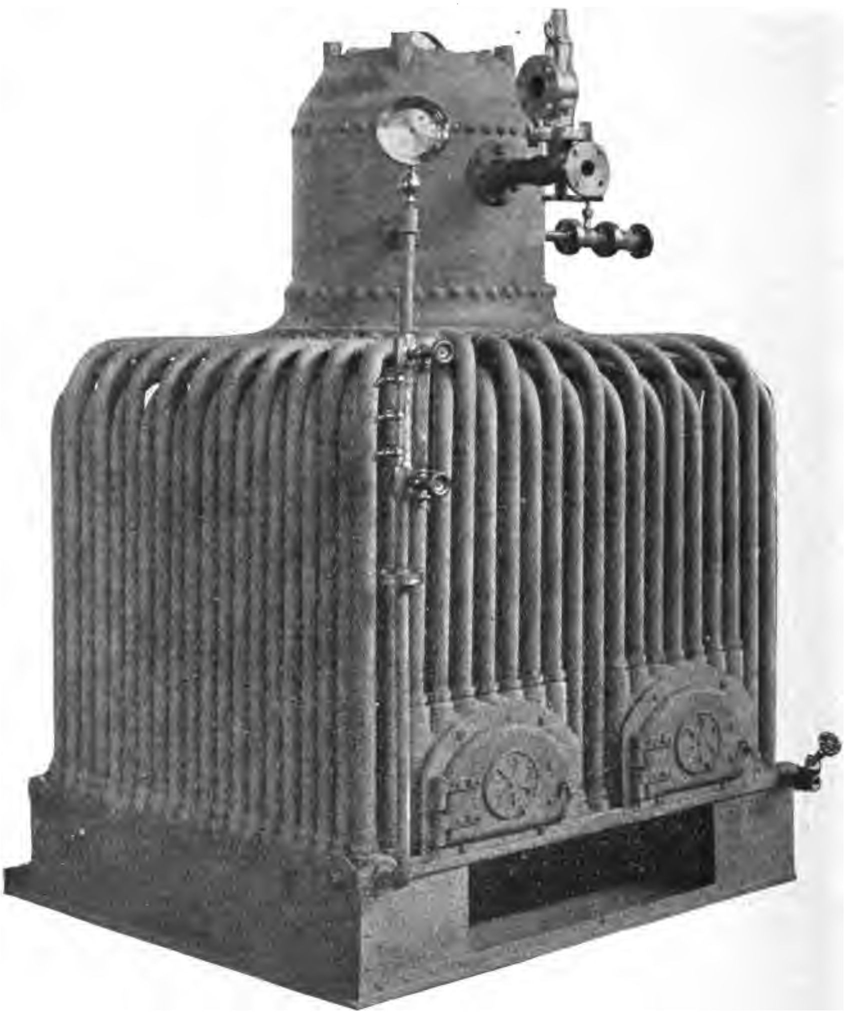


FIG. 120.

rounding the tubes and drum is a double casing, the inner one lined with asbestos or magnesia, and the space between the two forming an air space.

Fig. 120 shows the outside of the square type of this boiler, with

the casing removed. The construction is essentially the same, the lower manifold being square instead of circular.

Of the many other types of tubulous boilers which are used in foreign navies, three will be noticed here on account of the importance given them. The Belleville boiler has been extensively fitted to British, French and Russian battleships and large cruisers, the Dürr boiler finds considerable use in the German, and the Lagrafel-D'Allest boiler, in the French navy.

BELLEVILLE BOILER.

This is a sectional, straight, large-tube boiler, Fig. 121, which shows the latest or economizer type. There are two parts, the "generator" being the lower, and the "economizer," or feed water heater, the upper part.

The generator consists of a number of vertical sections of two rows of $4\frac{1}{2}$-inch tubes, connected at the top to a steam drum, and at the bottom to a small square water chamber or feed collector. Outside downtakes connect the ends of the drum with the ends of the water chamber. The generating tubes are inclined about $2\frac{1}{2}$ degrees to the horizontal, and zigzag in each section between the small connection boxes at each end of the tubes. There are two handholes in each front connection box for examination and cleaning. The circulation of the water in this part of the boiler is then downwards, from the ends of the drum, into the water chamber, thence upwards into and through the lowest tube of each section to the back connection box. Here it flows horizontally a short distance and enters the adjacent tube, through which it rises to the next highest front connection box, and thence into the adjacent tube and upwards, as just described. The last tube at the top discharges into the drum, well above the bottom, and the steam passes around numerous curved baffle plates into the stop valve nozzle near the top of the drum.

The economizer consists of a slightly smaller number of $3\frac{3}{4}$-inch tubes, similarly arranged and fitted as those of the generator, with small collectors for the tops and bottoms of the several sections. On the front of each boiler, there is a very complicated and delicate automatic feed regulator, which is an essential feature, and without which it is practically impossible to work the boiler. The water after leaving the special feed pump, at a very much higher pressure

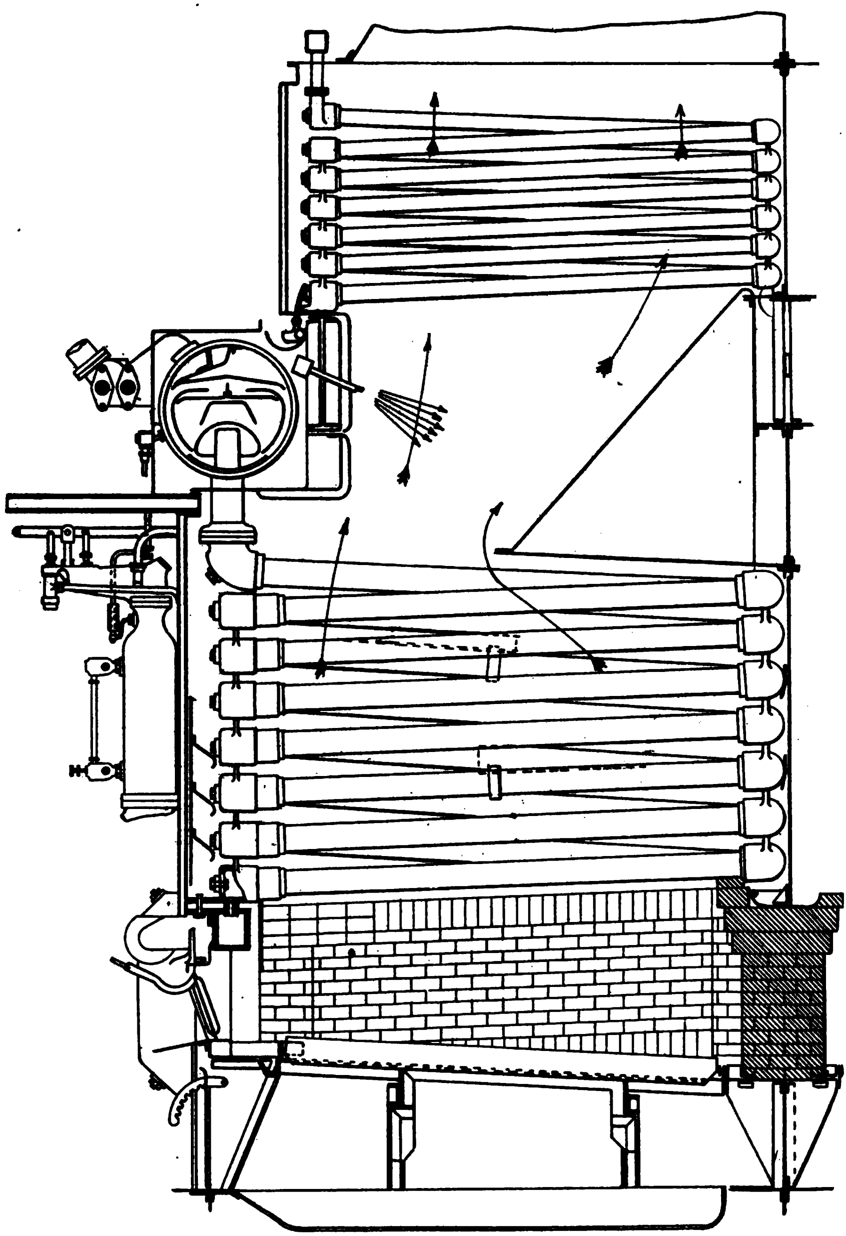


FIG. 121.

than that in the boiler, passes through the regulator and enters the lower collector of the economizer. In its upward course through the tubes it is heated by the waste gases, and passes from the top collector down to a check valve near the middle of the drum. After entering the latter, the water circulates as previously explained. Another attachment, not shown, but considered necessary, is a sediment collector on each side of the boiler, fitted between the lower end of each downtake and the corresponding end of the water chamber.

The furnace, except at the top, is built of fire brick. The gases of combustion pass up among the tubes, horizontal baffles being fitted as shown, and enter the space between the generator and economizer. Here numerous sprays of air, forced in under considerable pressure by an air compressor, mix the gases and help their combustion, before they pass up among the economizer tubes to the uptake. A similar gas mixer is fitted to the front of the furnace below. The fitting of economizers, which was shown to be a necessity, has resulted in much lower uptake temperatures, less production of smoke, easier methods of firing, and considerable economy. Reducing valves are usually fitted between the boilers and engines.

The tubes are secured in the connection boxes by screw joints, and to renew a tube, it is necessary to disconnect and remove the whole section from the boiler. The nut at the back end of the tube must usually be cut, as it cannot be unscrewed after a comparatively short service, and the same difficulty usually arises with the tubes too.

DÜRR BOILER.

This has large straight tubes, and, as shown by Fig. 122, is similar to the Niclausse boiler. The principal difference is that the front of the boiler is made box-shaped, the flat sheets of which must be held together by screw stays, and the sides and ends of which are riveted to the bottom of the drum. This construction is objectionable, and less satisfactory than separate headers.

The generating tubes are about 3¼ and 3½ inches in external diameter and are held in the tube sheet by cone joints. The front end of each tube is re-enforced, and bent to enter the tube sheet normally; the rest of the tube is inclined to the horizontal at an angle of 8°, and in some cases 10°. The back ends are closed by

a screw cap, and supported by a malleable iron grid, or a lattice of iron rods. Two rows of tubes on each side of the boiler are bent to

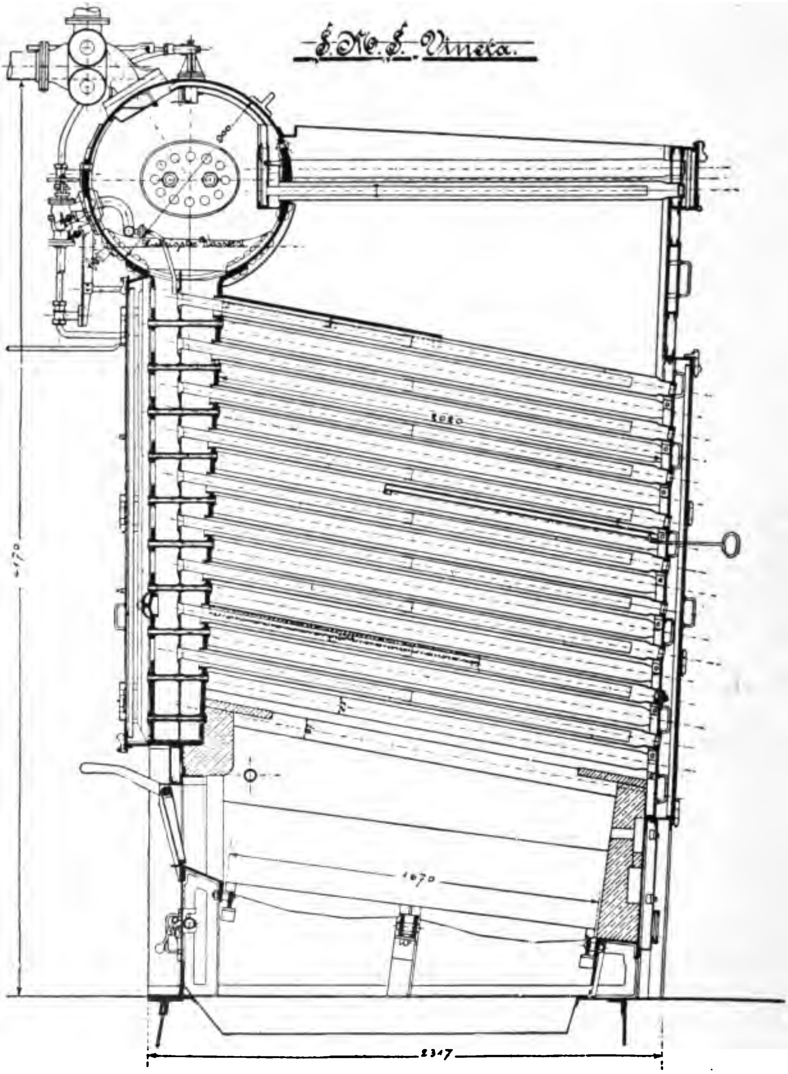


FIG. 122.

form a wall to reduce the loss of heat by radiation. The circulating tubes are held in the diaphragm by hooks fitted in slots. Opposite each tube is a handhole, the plate of which is fitted on the

D'Allest Boiler.

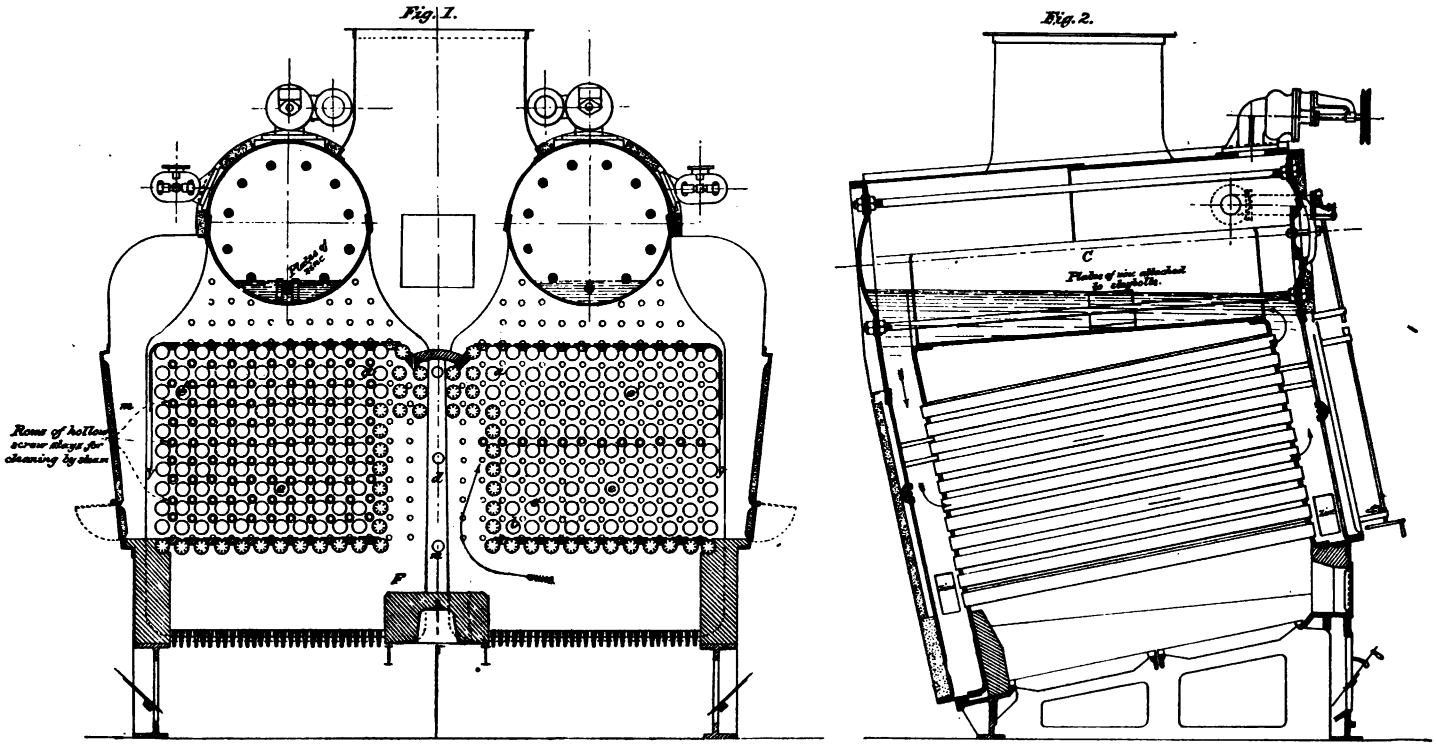


FIG. 123.

inside, a cone joint being used. Two rows of Field tubes, secured in the side of the drum, superheat the steam slightly and act as a steam drier. To prevent excessive corrosion in these thin tubes, when the boiler is not in use, they are inclined so as to drain into the drum.

Baffle plates are fitted among the tubes, as shown. In the latest design, a mud box is fitted below the front of the boiler. The furnace, except the top, is built of fire brick. The boiler is rather sensitive to priming when sea or brackish water is used. Like all boilers with slightly inclined tubes, they must be placed fore-and-aft in the vessel.

The instructions for firing this type of boiler require that thin fires be kept, from 4 to 5 inches, and that they be coaled regularly, about every five minutes under ordinary draft, with a charge of about 1.6 pounds per square foot of grate surface. For higher rates of combustion, the time between charges is reduced.

LAGRAFEL-D'ALLEST BOILER.

This is a straight, inclined-tube boiler, Fig. 123, with the axes of the steam drums in the same direction as the tubes, instead of across them. Each boiler is really a double one, the combustion chamber in the middle being the only part in common. Owing to its many stayed surfaces, the construction is objectionable.

The front and back of each boiler consist of box-shaped water spaces, which are formed of flat sheets riveted to the steam drum, the latter being cut away at each end, around its lower circumference, to open into the water spaces. The tubes are inclined, about $3\frac{1}{8}$ inches in external diameter, expanded in the tube sheets, and can be easily examined or renewed through the handholes opposite each tube in the outer plates of the water spaces. The heads of the drum must be stayed by through braces, owing to the great amount of material cut out of them below, and the flat surfaces of the water spaces must be stayed, as explained under shell boilers. Some of the screw stays are hollow, and are used for sweeping the tubes with steam or air. In later forms, these hollow stays are not fitted, the tubes being swept from the side.

The chief characteristics of this boiler are the combustion chamber and the consequent arrangement for conducting the gases. The combustion chamber extends the whole length of the grate, the sides

being formed by Serve tubes, the space at the top between the two boilers being bricked over. Experience has shown that the four upper rows of tubes must be extended across, in order to reduce the height of the combustion chamber. The top of the furnace is formed by a row of Serve tubes, on which rests a baffle of bricks, to direct the gases into the combustion chamber. The feed water is led by an internal pipe to the back water space. The ordinary check valve is used to regulate the feed, and the water level can be kept constant if the firing is regular. Owing to the construction of this boiler, steam must be raised slowly to prevent leaks, four hours being taken usually.

Zincs are put in all accessible parts and are considered essential. The builders recommend a thorough cleaning of the inside of the boiler every three months. Caustic soda, eleven pounds for every ton of water contained in the boiler, is dissolved in water and pumped in, care being taken that the concentration of this solution is not greater than one pound of soda for seven quarts of water, on account of the composition parts of the pump. A very light fire is then started, and about 30 pounds' pressure maintained for about two or three hours. The surface and bottom blows are then used, and, when the boiler is cold, it is drained completely. This cleaning will remove much of the oil. Additional cleaning and scraping, if found necessary by inspection of the tubes, is then done. Care must be used to get rid of the soda, as a small quantity of sea water in the presence of soda will cause priming.

CHAPTER XVIII.

BOILER TESTS.

For naval purposes, boilers are tested in order to determine the evaporative efficiency of different types under the same conditions, or of the same boiler under different conditions, and also to determine the value of fuels. To determine the evaporative efficiency, boilers are tested usually on shore and not connected to an engine; sometimes, boilers are tested in the ship and in connection with the engines. In order that the results of boiler tests for evaporative and fuel values may be compared, certain methods are followed, which are based on the "Rules for Conducting Boiler Trials, Code of 1899," adopted by the American Society of Mechanical Engineers. The order to the board which is to conduct the test gives the object of the trial, and such general and special instructions as may be necessary.

Before describing the various steps in a test and the instruments used, two general rules should be noted:

a. Take all measurements and observe all readings with great care and record them accurately. Inaccurate data are more than useless.

b. Give all the information and data that can be obtained, erring rather by giving too much than too little. It is much easier to get extra information at the time than it is to supply missing data later on.

1. *Description of the Boiler.*—Examine the boiler on the outside and inside, and obtain photographs, drawings, or blue prints, where possible. Check the dimensions of the grate and heating surfaces and all important parts, and make the corrections, if any, on the drawings. Describe the boiler and accessories fully, and illustrate special features by sketches or photographs. In computing the heating surface, use the outside diameter of the tubes.

2. Have the boiler thoroughly cleaned, and it and its appurtenances put in good condition, especially in regard to leaks.

3. Establish the correctness of all apparatus and instruments used in the test for weighing and measuring. These are:

a. Scales for weighing coal, ashes and water.

b. Tanks for weighing or measuring the water. Water meters will be used only as a check on the tank records. Whenever possible, *weigh* the water, to avoid the corrections for temperature when it is *measured*. There must be two tanks, each capable of holding from 1200 to 1800 pounds, or 20 to 30 cubic feet of water, and of being filled, weighed and emptied alternately, and a third tank below these from which the feed pump draws the water. The temperature of the water in each weighing tank should be taken at the top, middle and bottom, as it is run into the lower tank. The time it takes to empty each tank will be recorded. The temperature of the water in the lower tank should be taken each time that water is run in from the weighing tanks.

c. Thermometers and pyrometers for taking temperatures of air, steam, feed water, smoke pipe gases, etc. The thermometers must be graduated to one-tenth of a degree Fahrenheit.

d. Pressure gages, draft gages, etc.

4. Before starting a test, the boiler must be thoroughly heated to its usual working temperature. The brick work of tubulous boilers should be thoroughly dry, and the boiler worked long enough to heat the walls well.

5. The boiler and all connections must be free from leaks before beginning a test. All water connections, including blow and extra feed pipes, should be disconnected, and the openings closed with blank flanges, leaving open only the feed pipe which is to be used during the trial.

6. The conditions of the boiler and furnace in all respects should be, as nearly as possible, the same at the end as at the beginning of the test. The steam pressure and water level, the quantity and condition of the fire on the grate, and the temperatures of the walls, connections and uptake should be the same.

Two methods of obtaining the desired equality of conditions of the fire may be used, viz.: the standard and alternate methods. The latter is employed where it is not convenient to use the former.

7. *Standard Method of Starting and Stopping a Test.*—Steam being raised to the working pressure, remove rapidly all fire from the grate, close the damper, clean the ash pit, and, as quickly as possible, start a new fire with weighed wood and coal, noting the time and the water level while the water is in a quiescent state, just

before lighting the fire. The gage glass should not be blown through within an hour before the water level is taken at the beginning and end of a test, otherwise an error in this reading may be caused by a change in the temperature and density of the water in the pipe leading from the bottom of the glass to the boiler.

At the end of the test, remove the whole fire, which has been burned low, clean the grate and ash pit, note the level of the water when it is quiescent, and record the time of hauling the fire. If the water level is not the same as at the beginning, a correction should be made by computation, and not by working the feed pump after the test is finished.

8. *Alternate Method of Starting and Stopping a Test.*—The boiler being thoroughly heated by a preliminary run, the fires are to be burned low and well cleaned. Note the amount of coal left on the grate, as nearly as it can be estimated, the steam pressure, water level, and the time, the latter being recorded as the starting time. Now fire the furnace with fresh, weighed coal. The ash pits should be thoroughly cleaned immediately after starting.

Before the end of the test, burn the fires low, as before, and clean them, so that a bed of coal will be left on the grate of the same depth and in the same condition as at the start. When this has been done, note the time and record it as the stopping time. The water level and steam pressure should, before this, be brought to the same points, as nearly as possible, as at the start. Correction for difference in water levels should be made, as before, by computation and not by feeding.

9. In all tests made to ascertain the maximum economy or capacity of a boiler, the conditions should be maintained uniformly constant. The rate of evaporation may be kept the same, from start to finish, by allowing all or part of the steam to escape into the atmosphere, the pressure being regulated by the stop valve on the steam pipe. Uniformity of conditions should prevail as to the steam pressure, height of water in boiler, the rate of evaporation, the thickness of fire, the times of firing, the quantity of coal fired at one time, and the intervals between the times of cleaning the fire.

10. *Keeping the Log.*—Take note of every event connected with the progress of the trial, however unimportant it may appear. Record the time of every occurrence and the time of taking every weight and every observation.

The coal should be weighed and delivered to the fireman in equal

portions, each sufficient for not more than one hour's steaming, and a fresh lot should not be put out until all of the previous one has been fired. The time required to consume each portion is recorded at the instant of firing the last of each portion, recording at the same time the amount of water fed into the boiler, the height of water, and the average steam pressure and temperature of feed during that period. In order that the hourly periods may be complete, the fire room should be swept, and the coal remaining over from any portion should be weighed and allowed for at the end of the hour, the feed water up to that time being also checked. Then, in case the trial is suddenly stopped, on account of accident or other cause, computations can be made accurately up to the end of the last hour.

In addition to these entries, the regular records are made at the appointed intervals, usually every fifteen minutes for the more important data, and every half hour for the others.

When the standard method is used, the hourly rate of combustion and evaporation should be computed for the time that the fires are in active condition. This time is somewhat less than the actual time between the start and finish of the trial, owing to the loss of time due to kindling the fire at the beginning and burning it low at the end. The weight of wood used for kindling is added to the coal, on the assumption that one pound of wood equals 0.4 pound of coal.

11. *Sampling the Coal and Determining its Moisture.*—From each portion of coal, before it is weighed, a sampel shovelful is taken and put in a barrel or box in a cool place, and kept there until the end of the trial. These samples are then mixed and broken into pieces not exceeding one inch in diameter. This lot is then spread out evenly and divided into four parts, one of these quarters being retained for further mixing and crushing. This process of quartering and crushing is repeated until a final sample, weighing about five pounds, is obtained, and of which the largest piece will pass through a sieve with ¼-inch meshes. From this sample two 1-quart, air-tight jars, to prevent escape of moisture, are promptly filled. These samples are used in the determination of the heating value and chemical analysis of the coal, as well as of its moisture.

For anthracite and semi-bituminous coals, an approximately correct determination of moisture may be made by taking from the coal, after the above process of quartering and crushing has reduced

the sample to about 100 pounds, 25 or 50 pounds. This quantity is put in a shallow iron pan, not over 3 inches deep, carefully weighed, and then the whole placed on the hottest part of the boiler. It is left there for at least twelve hours and then weighed again. The loss in weight, expressed in per cent, gives the moisture.

But, whenever it can be done, and for all accurate tests, the following method should be used. Take the coal from one of the sample jars, weigh it, and then spread it in a thin layer in a warm room. After several hours' exposure to this air, weigh again, and the difference will give the surface moisture. Then crush the whole in a coffee mill to grains less than $\frac{1}{16}$ inch in diameter, mix thoroughly the crushed sample, and select from this from 10 to 50 grains. Weigh this small portion on scales which must show easily a variation of 1 part in 1000. Dry it in air or a sand bath at a temperature between 240 and 280 degrees Fahrenheit for one hour. Weigh and record the loss. Then heat and weigh again repeatedly at intervals of one hour or less, until the minimum weight is reached, and it begins to increase by the oxidation of a portion of the coal. The difference between the original and the minimum weights is taken as the moisture of the *air-dried* coal. The sum of this percentage and of the percentage of surface moisture is the total moisture. To prevent inaccuracy, this test should be made in duplicate. The two results should agree within .3 to .4 of one per cent, and the mean is then taken as correct.

12. The ashes and refuse from the coal used are weighed dry. If required, a characteristic sample should be subjected to a proximate analysis to show the actual amount of incombustible material. The quantity of dry coal, less that of dry ash and refuse, gives the total quantity of *combustible* consumed.

13. *Analysis and Calorific Tests of the Fuel.*—The analyses of the fuel should be made by an expert chemist only. The "ultimate" analysis of the dry coal shows the percentages of C, H, O, N, S and ash. The "proximate" analysis gives the proportions of fixed carbon, volatile matter, moisture and ash, and these indicate the character of the fuel.

As already explained under "Combustion," the total heating value of the fuel, as computed from the ultimate analysis by the use of Dulong's formula, is not very accurate. This value is best obtained by means of a fuel calorimeter, in which the sample is burned in an atmosphere of oxygen gas, sufficient for perfect com-

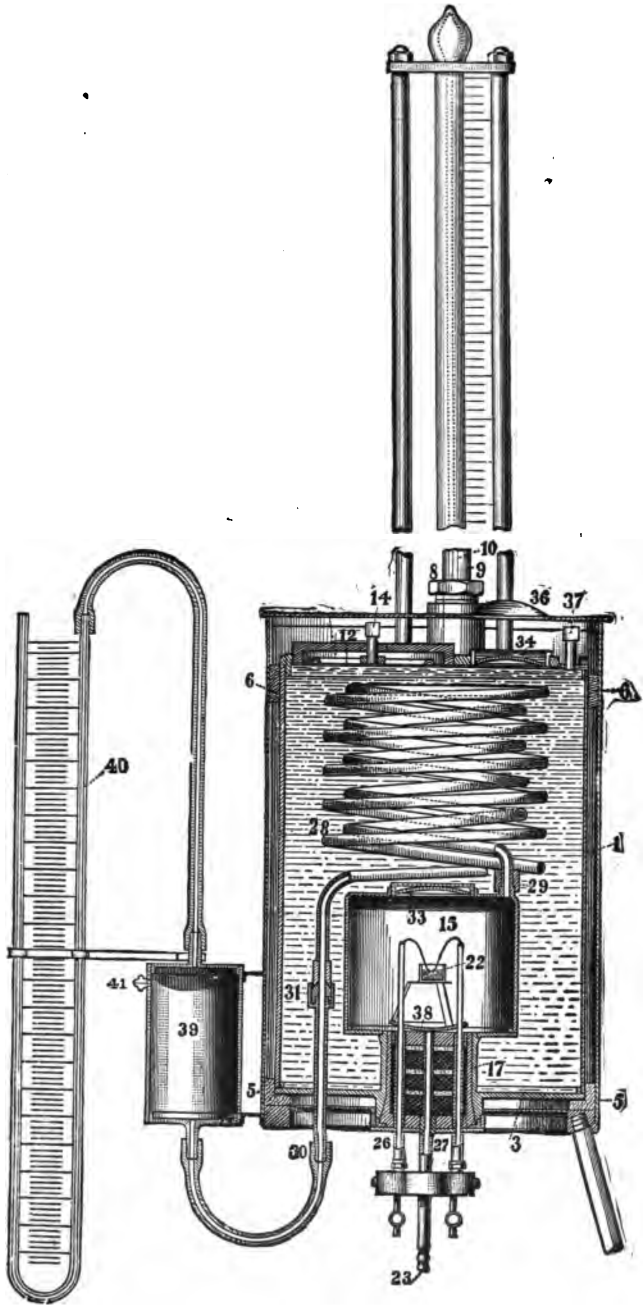

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FIG. 124.

bustion, and the heat evolved by this combustion is absorbed and measured.

CARPENTER'S COAL CALORIMETER.

One form of these calorimeters, patented by Prof. R. C. Carpenter, is shown by Fig. 124. The heat generated is absorbed by water and measured by its expansion.

The fuel is burned in the combustion chamber 15, which is surrounded by the large closed chamber 1, filled with water. The latter is able to expand into the open glass tube 9, to which a scale 10 is attached. The combustion chamber can be opened at the bottom by removing the plug 17. This plug carries a small asbestos cup 22, in which the fuel is placed; a silver mirror 38, to deflect any radiant heat; two wires 26 and 27, insulated by vulcanized fibre tubes, and connected at the tops by a thin platinum wire, to convey an electric current for firing the fuel; and the central tube 23, through which the oxygen for combustion is supplied. The plug is made of alternate layers of rubber and asbestos fibre, surrounded by a metal casing; as this metal is in contact with the wall of the water chamber, it can transfer little or no heat to the outside.

The products of combustion pass out of 15 into and through the double spiral copper coil 29, 28 and 31, which ends in the nipple 30. From this a hose connection is made to a small chamber or reservoir 39, which is attached to the outer case, and provided with a siphon gage 40, to indicate the pressure of the gases. A plug 41, with a pin hole, is attached to 39 for the discharge of the gases. The process of combustion can be watched through the glasses 33, 34 and 36, secured in the tops of the combustion chamber, water chamber and outer case, respectively. The combustion chamber can be subjected to considerable pressure, but usually a pressure corresponding to 10 inches of water is sufficient to give reliable results. Two grams of coal can be burned at a time in cup 22.

In the top of the water chamber 1, there is a diaphragm 12, by means of which and the screw 14 the zero level in the glass tube 9 can be adjusted. The chamber, which will hold about five pounds of water, is filled and emptied through the hole which is closed by plug 37. A metal case, nickel-plated and polished on the inside to reduce radiation, slips over the water chamber, which is supported on strips of felting 5 and 6.

Compressed oxygen gas can now be bought in small iron flasks; the pressure in the flask may be reduced to the amount desired for

the calorimeter by the interposition of a small gasometer. This can easily be made by inverting one pail into another one partly filled with water. By weighting the top pail, any pressure can be obtained. The oxygen must be supplied to the calorimeter at a *constant pressure.*

The platinum wire may be heated by an incandescent light circuit, if sufficient resistance is introduced, or by a single cell of a storage battery, the current of which is ordinarily used for incandescent lighting. The patentee uses 16 Mesco dry batteries connected in four series. The cup 22, in which the fuel is burned, can be made by wrapping a piece of sheet asbestos about the end of a small cylinder, and using a weak glue to hold it in cup shape. The cup is then subjected to a white heat to remove all combustible matter. In this state, asbestos will readily absorb moisture, and care must, therefore, be used to thoroughly dry the cup before it is weighed at the beginning of a test.

With each calorimeter, there is a *calibration* or standardization *curve,* which may be used in determining the heating value of the fuel sample, but only, when all the conditions under which the calibratation was made are maintained during the test. The two most important conditions are the pressure under which the combustion takes place, and the identity of the glass tube in which the water expands. If a different gas pressure is used during the test, or a new glass tube is inserted, the calorimeter must be calibrated anew, as will be explained later.

Method of Using the Calorimeter.—a. From the samples of the fuel, obtained as shown in Section 11, take enough coal, by further quartering and crushing, to give several samples in a *powdered state.* Place one of these samples (about 1½ or 2 grams) into the dry asbestos cup of known weight, and weigh accurately. The water chamber has been previously filled and the level in the glass tube adjusted, as will be explained under the "Method of Calibration."

b. Have the temperature of the room, in which the test is made, less than 80° F., as the calorimeter must always be warmer than the surrounding air.

c. Put the weighed charge of dry fuel into the calorimeter, adjust the platinum wire *above* the fuel, make battery connections, and, so soon as the heat from the fire causes the water in the glass tube to rise, turn on the oxygen, and fire the charge by pulling the heated wire down to the fuel. The instant that the fuel is lighted,

break the current, and note the reading of the scale 10 and the time. Keep 41 open during combustion, occasionally clearing it with a wire.

d. Watch the combustion, which will require usually about ten minutes for each grain of coal. When completed, shut off the oxygen and note the reading of the scale and the time. The difference between the second and first readings is the "actual" scale reading.

e. Allow the calorimeter to stand for a time equal to that of combustion, and then note the fall of the water and the time. The difference between this and the second reading is the correction for radiation, and is added to the "actual" reading to get the "corrected" scale reading.

f. From the calibration curve, find the heat value of the sample corresponding to the "corrected" scale reading, and divide this number of heat units by the weight of the sample in pounds. The result will be the heating value of oue pound of the fuel in B. T. U.

g. To determine the ash, weigh the asbestos cup, in which the combustion took place, with and without its contents. The difference between the two gives the weight of ash.

h. Wipe the combustion chamber dry for another determination. Remove the calorimeter from its case and immerse it in cold water for a few minutes, care being taken to prevent the entrance of any water into the combustion chamber or oxygen tube. This method is preferable to emptying the calorimeter and filling it with fresh water for each test, as it prevents the introduction of air with the water.

i. Repeat the test on at least two more samples.

Example:

Weight of crucible	1.269	grams.
" " " and coal	3.017	"
" " " and ash	1.567	"
" " combustible	1.450	"
" " ash	.297	"
" " coal	1.747	"

1.747 grams = 1.747 x .002205 = .003852 pound.

First scale reading,	3.90 inches,	time 2 o'clock,	55 minutes.	
Second " "	14.70 "	" 3 "	20 "	
Third " "	14.30 "	" 3 "	45 "	

Actual scale reading, 14.70 — 3.90 = 10.80 inches.
For radiation, 14.70 — 14.30 = .40 "
Corrected scale reading, 11.2 "

On the calibration curve, 11.2 corresponds to 46.25 B. T. U. in the sample.

As there are 46.25 B. T. U. in .00385 pound, one pound will contain $46.25 \div .00385 = 12{,}000$ heat units.

It should be noted here that, in burning coals which have a large per cent of volatile matter, the water resulting from the combustion often affects the rate of flow of the burnt gases through the copper coils, and changes the reading of the siphon gage. Should the reading of this gage not remain approximately constant, the result obtained is of uncertain value.

Method of Calibration.—The curve is obtained by burning different weights of pure carbon under a constant pressure of oxygen, and noting the corrected scale readings, and then plotting the number of heat units in each weight of carbon as abscissae, and the number of inches in the corresponding corrected scale reading as ordinates. The heat value of one pound of pure carbon is taken as 14,600 B. T. U. To give accurate results, all air must be removed from the water in the chamber, and the gas pressure kept constant.

To make the pure carbon, powder some charcoal obtained from sugar or soft coal. Fill a porcelain or clay crucible one-third full, cover it tightly, and then heat with a blast lamp or in a forge fire for one-half hour. When cold, grind the coke thus produced to a very fine powder in a mortar. Obtain other samples by repeating this operation.

Fill the calorimeter chamber with water, close the screw plug 37, and connect the glass tube opening, by a rubber hose or glass tube, to a smaller vessel filled with water. Boil the water in the calorimeter, using a Bunsen burner, and protecting the instrument by a thin sheet of asbestos. Keep the tube opening the highest point of the instrument, so that all air or steam may pass through the rubber or glass connection to the smaller vessel. Keep the water in the latter boiling until the calorimeter has entirely cooled, then remove the rubber connection, and insert the open glass tube, taking care that it does not pass so far into the water chamber as to trap any air. Partly fill the tube with boiled water, and seal the surface of this water from the air with about two inches of kerosene. If, after the calorimeter has taken the temperature of the room, the water column is too high, allow sufficient water to leak

out slowly through the screw plug 37, until the scale reading is about two inches.

The calorimeter is now full of water freed from air, and the carbon samples can then be burned by following the method previously given for using the calorimeter. The difference between the weights of the crucible and carbon and of the crucible and ash is, in each case, the weight of pure carbon burned. Reducing this to pounds and multiplying by 14,600, we get the number of heat units in the sample. Plotting this and the corresponding corrected scale reading for each weight of carbon burned, we get the calibration "curve," which should be a straight line with the origin at zero.

14. *Analysis of Smoke Pipe Gases.*—The object of this analysis is to determine the relative value of different methods of firing, or of different kinds of furnaces. From the escaping gases, we can judge, approximately, whether the air supply to the fire is greater and how much greater than that necessary for complete combustion, whether the combustion is complete, the approximate losses due to each, and whether the furnace and its arrangement are such as to burn the fuel with the greatest advantage. These points are obtained from the proportion of CO_2, O and CO in the escaping gases, the other constituents, such as H_2O, H and any unburned hydrocarbons, which are not measured, being neglected for all ordinary purposes. The proportion of nitrogen is obtained by difference and includes all the combinations of hydrogen.

In making these analyses, great care must be taken to procure average samples often and for a considerable period of time, as the composition of the gases is liable to vary at different points of the uptake and from minute to minute. The samples should be drawn from the uptake, near the place where the temperature is measured, by an aspirator or bellows, preferably a steam aspirator, through a perforated pipe, closed at its inner end, and which extends across to the center of the uptake. The samples are delivered, at will, directly into an apparatus where the principal gases are absorbed and measured, or, first, into a collecting bottle. The latter is used only when an average sample for any period of time is to be obtained. The aspirator can be made easily out of pipe fittings and must have a short discharge into the air. By means of a T-connection between the suction side of the aspirator and the gas testing apparatus, a correct sample can be obtained conveniently.

Two kinds of apparatus are used for the gas analysis in naval boiler tests, the Elliott, said to be for rapid work, and the Orsat-Muencke. The former is simpler in construction, but requires greater care and expertness in using it. The other apparatus is convenient, more easily portable, and less liable to breakage.

ELLIOTT'S APPARATUS.

One form of this is shown by Fig. 125. There are two glass tubes, A and B, with capillary tubes at their tops, which are connected by rubber tubing at E. A capillary extension at the top of A is fitted with a removable funnel M. The larger tube A, which may be called the treating tube, holds about 125 cubic centimeters; tube B, or the measuring tube, holds 100 c. c. between the marks at C and D, and is carefully graduated to fifths of a cubic centimeter. The lower ends of A and B are connected by rubber tubing to the open water bottles L and K, respectively, a three-way cock I being fitted to A. Stop cocks F and G are fitted to the tops of these tubes.

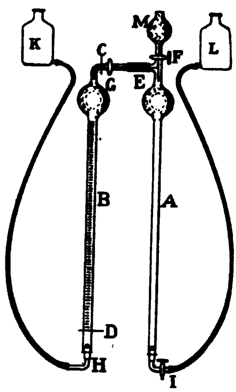


FIG. 125.

In beginning the analysis, I is turned to connect A and L, F and G are opened, and water is allowed to fill the apparatus from K and L. When the water rises in M, and all the air bubbles have been driven out of the tubes, F and G are closed, M is removed, and the tube delivering the gas from the aspirator or collector attached in its place.

Bottle L is now lowered slowly, with F open, and tube A nearly filled with gas, after which F is closed. The gas delivery tube is then replaced by M, G opened, and, by simultaneously raising L and lowering K, part of the gas is transferred from A to B. By first adjusting K, so that the water level in it is the same as the zero-mark D, and then L, exactly 100 cubic centimeters can be separated in B by closing G. It is advisable to wait some minutes before making the final adjustment, in order that the gas may have the same temperature as the apparatus. The rest of the gas in A is then discharged through F by raising L, the small portion remaining in the capillary tubes beyond C being disregarded. In

measuring the gas, it must be remembered that this volume must be under atmospheric pressure, hence the water level in K must be the same as that in the measuring tube, whenever readings of volumes are taken.

The 100 c. c. of gas are now transferred back from B to A, by manipulating the bottles K and L. Then the first re-agent or absorbent is put in the funnel M, and, by adjusting F, allowed to flow slowly down the *sides* of A, in order to expose the gas to a large absorbing surface. Care must be taken never to let the level of the re-agent in M get below the level of the top of the vertical capillary tube above F; this can be prevented by making a mark on the outside of M, about three-fourths of an inch above the top of the tube, and never drawing the re-agent below this. Should, however, some of the re-agent get into the horizontal capillary tube, it should be removed by passing a little water from K.

After allowing several minutes, for the absorption of the gas by the re-agent, transfer the gas to the measuring tube, adjust the fluid in A to the mark C on the horizontal tube, and then close G. Now adjust water level in K to that in B, allowing a few moments for the water on the sides of B to settle, and then take the reading of the reduced volume of gas in B. The loss in volume is equivalent to the percentage of the particular gas absorbed.

Before repeating the above operation with a new re-agent for another gas, it is necessary to clean the treating tube thoroughly. The mixture of water and re-agent in A are first run out, by setting I so that the discharge through its stem will be open to the air, and opening F. Water is then run through by filling M. When A is clean, set I to connect A and L, and force the water up to the mark at C. The apparatus is now ready to receive the gas in B for a new treatment, care having, of course, been taken that no gas is allowed to escape nor air to enter.

Use of Re-agents.—The re-agents or absorbents must always be used in the following order.

1. Potassic hydrate, to absorb the CO_2 or carbon dioxide. This is a solution in distilled water of from 3 to 5 per cent of white, caustic potash, which comes in sticks.

2. Potassic pyrogallate, to absorb the free oxygen. This re-agent is prepared by mixing a strong solution of potassic hydrate with 3 per cent solution of pyrogallic acid. It will take about five minutes to absorb the oxygen.

3. Cuprous chloride solution in concentrated hydrochloric acid, to absorb the CO or carbon monoxide. This solution keeps best in a bottle containing some pieces of clean copper wire. After using this solution, and *before* the gas is transferred to the measuring tube, water is added to completely wash the sides of A and absorb the acid vapors. The absorption of CO takes longer than that of the O.

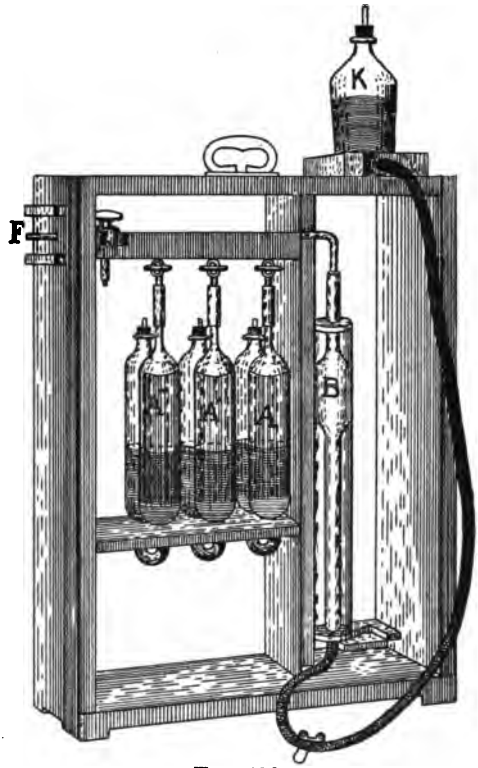


FIG. 126.

A complete analysis will take about twenty minutes with an expert operator. The water used in the apparatus should have the same temperature as that of the room. When working in a warm place, B should be surrounded by a water jacket to prevent change of volume in the gas while under treatment.

ORSATT-MUENCKE APPARATUS.

This is shown by Fig. 126, in which B is the measuring tube, surrounded by a water jacket and connected to the single levelling

bottle K. The re-agents, instead of being put into one tube successively, are now kept in separate treating pipettes, A, A′, A″. These are U-shaped, one end being connected by rubber tubing and a stop cock to the pipe which supplies the gas to B from F, and the other end being open to the atmosphere. To increase the absorbing surface of the re-agents, the pipettes are filled with glass tubes. The re-agents are the same as before, except that the potassic hydrate absorbent is usually about one part caustic potash in two parts of water. The order in which the gases are absorbed is the same, the reagent for CO_2 being in the pipette A nearest the measuring tube.

In beginning an analysis, the re-agents must be adjusted in the capillary tubes, so that the level will be about half way between the top of the pipette and the rubber connector. Then, after the apparatus has been connected to the aspirator, and the levelling bottle has been filled with water, draw enough gas into the measuring tube to fill it, by lowering the bottle and opening the top pipe to the aspirator connection. This gas is then discharged by raising the bottle, the apparatus and connections being thus cleared of air.

Now draw in 100 c. c. of the gas, observing the same precautions in measuring as given above. Then open the cock on the first pipette, and allow the re-agent in it to absorb the carbon dioxide, by running the gas in and out of the pipette about four times. At the last time, the re-agent must be allowed to fill the leg next to the measuring tube completely. A rubber bag is usually provided for the purpose of causing alternate suction and pressure in the open end of the pipette, and to keep the air from the re-agent. In order to be sure that the absorption of CO_2 is complete, the test should be repeated until the last reading agrees with the first to within 0.1 per cent. The same must be done with the tests for O and CO, except that in the last case, the readings must agree exactly.

After the absorption of CO_2, and the return of the remaining volume of gas to the measuring tube, wait one minute before taking the reading, in order to let the water from the sides of the tube drain down. Owing to the water jacket on the measuring tube, two meniscuses will appear when looking at the scale. So long as the same meniscus is read for the whole analysis, no difference will be made. It is best to read the bottom of a meniscus always.

The operation is next repeated for the absorption of the O, and

then for the CO, each requiring a longer time than the preceding one. The reduction in volume each time is, as before, the percentage of the particular gas in the mixture as drawn from the smoke pipe, the remainder, after those gases have been absorbed, being classed as nitrogen. When transferring the gas during these operations, do not let the re-agents, especially the caustic potash or pyrogallate, get into the measuring tube, as the water in the bottle must then be changed. Should a little water be allowed to get into the treating pipettes during a transfer, it will do no harm. About twenty minutes are required for an analysis by an expert with one apparatus. If two apparatus are used, two analyses may be made in twenty-five minutes.

Deductions from Results of Gas Analysis.—The presence of CO in the smoke pipe gases shows that the combustion is imperfect. With ordinary combustion and moderately high uptake temperatures, the amount found is very small, being within one per cent.

If free oxygen is found without CO, it shows that too much air is supplied. According to Bertin, if from 1.5 to 2 per cent of oxygen is found, the fire is too heavy and the rate of combustion too high, as regards efficiency, for the draft employed; if it exceeds 8 per cent, the fire is too thin, the draft too great, or the air passages above the grate too large; if between 2 and 8 per cent, the air supply is right. CO and O appearing together prove that the air and combustible are not completely mixed, or that the temperature of the furnace is so low as to check combustion. If the two gases are present in excess, the boiler itself is at fault.

Calculations from Results of Analysis.—The weight of dry gases, per pound of fuel as fired, is calculated from the analyses of the gases and the fuel, and from that the number of pounds of dry air passing through the furnace per pound of fuel is found. An approximate heat balance can then be compiled, showing the losses in the heating value of the fuel due to the several causes. The heat units utilized are obtained from the results of the evaporative test of the boiler. In order to make the results comparative, the computations are based on the pound of combustible.

Suppose that the analysis of the gases showed, in per cent, 12.7 CO_2, 5.7 O, 0.5 CO, and 81.1 N, by difference, and that the chemical analysis of the coal as fired gave, in per cent, 83.5 C, 4.8 H, 3.2 O, 1.2 N, 0.5 S, 1.5 moisture, and 5.3 ash. The calorific value of one pound of the *dry coal* was found to be 14,580 B. T. U., by

coal calorimeter. The analysis of the coal, referred to *combustible*, i. e., coal less the ash, would then be, in per cent, 88.2 C (83.5 x 100 ÷ 94.7), 5.1 H, 3.4 O, 1.2 N, 0.5 S, and 1.6 moisture. The calorific value of one pound of dry combustible was found to be 15,640 B. T. U.

By Avogadro's hypothesis, the weight of a gaseous compound is equal to its molecular weight, referred to hydrogen as unity. The chemical equivalent by volume of CO and CO_2 is 2, and of O and N is 1, referred to hydrogen as unity, or, the molecular weights of H, O and N are twice their atomic weights. The weight of dry gases will, therefore, be the percentage of each gas found in the analysis multiplied by its molecular weight, or

Pounds of dry gas $= \%CO_2 \times 44 + \%O_2 \times 32 + \%CO \times 28 + \%N_2 \times 28.$

The pounds of dry gas, per pound of carbon, will then be this amount divided by the product of the atomic weight of carbon and the sum of the percentages of the carbon bearing gases. This is deduced as follows:

Weight of gases containing carbon $= CO_2 \times 44 + CO \times 28.$

Since $\frac{3}{11}$ of the CO_2 and $\frac{3}{7}$ of the CO is carbon, therefore,

$$\frac{3 \times CO_2 \times 44}{11} + \frac{3 \times CO \times 28}{7} = 12\ (CO_2 + CO).$$

Letting the symbols represent the percentages, by volume, then Pounds of dry gas per pound of carbon burned

$$= \frac{44CO_2 + 32O + 28CO + 28N}{12(CO_2 + CO)} = \frac{11CO_2 + 8O + 7(CO + N)}{3(CO_2 + CO)}.$$

Substituting the percentage values from the gas analysis given above, we get,

Dry gas per pound of carbon

$$= \frac{11 \times 12.7 + 8 \times 5.7 + 7\ (81.1 + .5)}{3(12.7 + .5)} = 19.1 \text{ pounds.}$$

The number of pounds per dry gas per pound of combustible = pounds of gas per pound of carbon multiplied by the percentage of carbon (in decimals) in the combustible.

Or, in this case,

Dry gas per pound of combustible $= 19.1 \times .882 = 16.85$ pounds.

The number of pounds of dry gas per pound of coal as fired = pounds of gas per pound of carbon multiplied by percentage of carbon (in decimals) in the coal.

The gas analysis accounts for the carbon only, and we must, therefore, add the H_2O in the gases, formed by evaporating the moisture and by burning the H in the coal. The latter we find on the same principle as above, and the former, from the coal analysis. Hence,

$$H_2O \text{ from hydrogen in coal} = \frac{4.8 \times 9}{83.5} = .52 \text{ pound.}$$

$$H_2O \text{ from moisture in coal} = .053 \times .835 = .04 \text{ pound.}$$

$$.56 \text{ pound.}$$

Or, the total weight of gases per pound of carbon $= 19.1 + .56 = 19.66$ pounds; per pound of combustible $= 16.85 + .56 = 17.41$ pounds; and per pound of coal as fired $= 19.66 \times .835 = 16.37$ pounds.

The quantity of *air* which passed through the furnace for each pound of combustible is, therefore, $17.4 - 1 = 16.4$ pounds. The air per pound of coal is only approximately one pound less than the gas per pound of coal.

Loss by Heat of Gases.—Suppose that the temperature of the the gases in the uptake or smoke pipe was 590°, and that of the external air, 75° F. For all practical purposes, and in view of the approximate results which can be obtained by the present state of the art of gas analysis, the average specific heat of the dry gases may be taken as .24, and of the dry gases including the H_2O, as .246.

The rise in temperature is 515° F. As there were 17.41 pounds of gases for each pound of combustible, the sensible heat loss was, $(17.41 + .246) \times 515 = 2206$ heat units per pound of combustible (1).

Loss Due to Latent Heat in H_2O.—The loss of sensible heat in the steam gas has been accounted for in the above calculation, but in addition, there is the loss of heat rendered latent by changing the H_2O, formed from the H and H_2O in the coal, from water into steam. The latent heat of one pound of steam under atmospheric pressure is 965.8. It was found above that .56 pound of H_2O gas was evolved from the coal. The loss is, therefore,

$.56 \times 965.8 = 541$ heat units per pound of combustible (2).

Loss Due to Incomplete Combustion.—As we have found before, the weight of the carbon in the gases is $12(CO_2 + CO)$. The

perfect or complete combustion of this total carbon would have given $12(CO_2 + CO) \times 14{,}600$ heat units $= a$. But the combustion of the carbon, as shown by the gas analysis, was only partially complete, and the heat generated was, therefore, only $12CO_2 \times 14{,}600 + 12CO \times 4400$ units $= b$. The difference between the two will give the loss in heat units due to the incomplete combustion, or, Loss $= a - b = 12CO \times 10{,}200$ heat units, or, in per cent of a,

$$= \frac{12CO \times 10{,}200 \times 100}{12(CO_2 + CO)} = \frac{CO \times 10{,}200 \times 100}{CO_2 + CO} \text{ per pound of carbon.}$$

And per pound of combustible,

$$\text{Loss} = \frac{CO \times 10{,}200}{CO_2 + CO} \times \frac{\%C \text{ in combustible}}{100}.$$

Substituting values from the above gas and chemical analyses, we get loss due to incomplete combustion, per pound of combustible,

$$= \frac{.5 \times 10{,}200}{12.8 + .5} \times \frac{88.2}{100} = 341 \text{ heat units, (3).}$$

Suppose that the results of the evaporative test of the boiler gave 11.6 pounds as the equivalent evaporation from and at 212° F. per pound of combustible. Then,

$$11.6 \times 965.8 = 11{,}203 \text{ heat units absorbed by boiler, (4).}$$

From this and the losses computed above, we can make up a heat balance which will show the approximate distribution of the heating value of one pound of the combustible.

Calorific value of the combustible..........		15,640 heat units.
Absorbed by the boiler...........	11,203	
Loss due to sensible heat in waste gases	2,204	
Loss due to latent heat in steam gas	541	
Loss due to incomplete combustion,	341	
Other losses, due to radiation, etc., by difference	1,351	
	15,640	

These values are frequently expressed in per cent of the calorific value of the combustible.

15. *Smoke Observations.*—In order to have a uniform system of determining and recording the density of smoke produced, the

smoke chart invented by Prof. Ringelmann is now used. There are six cards, four ruled into small squares by lines of varying thicknesses, one entirely white, and another, solid black. They are numbered from 0 to 5, and are hung in horizontal row about fifty feet from the observer and, as nearly as convenient, in a line with the top of the smoke pipe. At this distance, the lines on the ruled cards are not visible, and the cards appear to be of different shades of gray, ranging from very light gray to almost black. The observer glances from the smoke to the cards and determines which one is nearest in color to that of the smoke. The number of the card and the time is then recorded. The observations should be frequent. The whole number of observations may then be plotted on cross section paper, to show the variation in the smoke from time to time, and the average of all the records is taken as the average density for the test.

The ruled cards have usually seventeen horizontal and ten vertical lines, spaced 10 mm. apart between centers. The thickness of the lines is 1, 2.3, 3.7, and 5.5 mm. for cards Nos. 2, 3, 4, and 5, respectively, the white spaces left between the lines decreasing, therefore, from 9 to 4.5 mm. square.

16. *Quality of the Steam.*—It has already been shown, under "Evaporation," that, if there is moisture or water in the steam produced, the total heat will be less than that of dry steam, and that the proportional weight of dry steam in the mixture of steam and water, is called the "Quality of the Steam," and is designated by Q. For wet steam, Q is, therefore, always less, and, for superheated steam, always greater than unity. In order that the efficiency results of a boiler, as determined by trial, may be of value, it is necessary to know the quality of the steam produced, or in other words, the amount of moisture in the steam must be determined. This is done conveniently by the use of some form of *throttling* or *separating steam calorimeter,* or a combination of both.

The throttling calorimeter was first designed by Prof. C. H. Peabody; the later forms, of which Prof. R. C. Carpenter's throttling calorimeter, Fig. 127, and the upper part of Mr. W. H. Barrus' universal calorimeter, Fig. 128, are examples, differ only in size and form. For all ordinary types of high pressure boilers, in which the steam produced at normal rates of evaporation rarely

contains as much as 2 per cent of moisture, the throttling calorimeter is sufficient and accurate; its limits of usefulness vary from about 2.5 per cent, when the pressure of the entering steam is 100 pounds, to about 7.5 per cent at 300 pounds absolute. Should the moisture exceed these limits, no computation could be made, and a separating calorimeter, or the separator attachment shown by the lower part of Fig. 128, must be used.

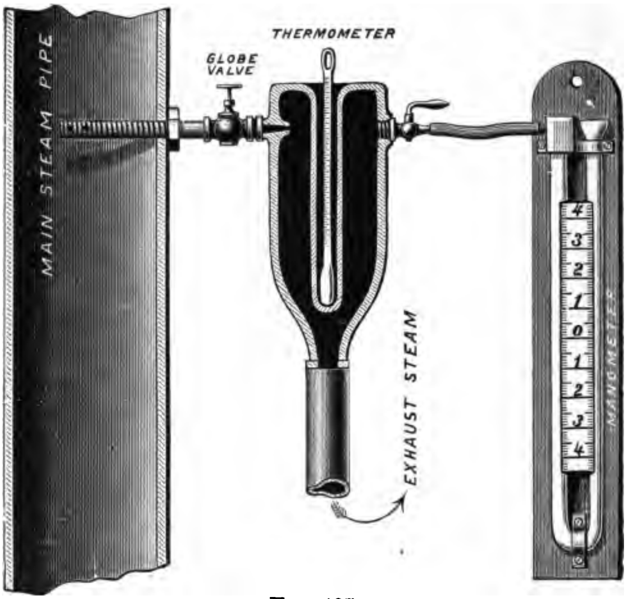


FIG. 127.

CARPENTER'S THROTTLING CALORIMETER.

This, Fig. 127, is small and easily portable, and consists of a brass vessel. nickel-plated, which has in its center a deep cup, into which a thermometer can be inserted. Steam is supplied to this vessel through a tapering hole near the top, and is discharged directly into the atmosphere through an opening at the bottom, or through a valve in the exhaust pipe. A manometer or gage, for measuring the pressure in the interior, can be attached to a cock fitted to the calorimeter near its top, when a pressure in the calorimeter greater than that of the atmosphere is desired.

In order to obtain an accurate average sample of the steam generated, the sampling nozzle in the main steam pipe from the boiler

is made as follows for *all* forms of calorimeters: The nozzle is placed in the *vertical* part of the main steam pipe and is made of a $\frac{1}{2}$-inch pipe, which extends across the steam pipe to within $\frac{1}{2}$ inch of the opposite side. It is closed at that end and perforated with many, but not less than twenty $\frac{1}{8}$-inch holes, equally distributed along and around its cylindrical surface, but none of these holes must be nearer than $\frac{1}{2}$ inch to the inner side of the steam pipe. A stop valve, preferably a gate valve, is fitted between the outer end of the nozzle and the calorimeter; this valve is not a part of the calorimeter, but is used merely to shut off or turn on steam.

The calorimeter and the pipe to it from the nozzle are well covered with felt, and the former should be attached to the steam pipe as close as possible. A steam gage, to show the pressure in the main steam pipe, and a barometer, to show the pressure of the atmosphere, complete the calorimeter outfit. The manometer is a U-tube filled with mercury and shows the excess of pressure in the calorimeter above that of the atmosphere, in inches of mercury, which reading is reduced to pounds per square inch by dividing it by 2.04.

Using the Calorimeter.—Attach the calorimeter as shown in the figure, observing the precautions given above. Fill the thermometer cup about one-third full with cylinder oil and insert the thermometer. Open the stop valve wide, and allow the steam to flow through the calorimeter for at least ten minutes before any readings are taken. Stop all leaks in the apparatus and connections. As calorimetric observations are taken every fifteen minutes during a test, the valve is kept open until the end of the test. For an observation, note quickly the readings of the thermometer in the calorimeter, manometer, steam gage and barometer, and record these with the time.

Calculation of the Quality of Steam.—To understand the calculations, we must first understand the principle on which the throttling calorimeter works.

When steam is *throttled* or *wire-drawn*, by means of any device which reduces the opening for the passage of the steam, the pressure beyond the throttling device will be less than that on the boiler side. In the Carpenter calorimeter, the steam is throttled by the tapering orifice near its top, and the pressure in the calorimeter is, therefore, less than in the main steam pipe. It has been found by experiment that no allowance need be made for radiation,

if the orifice is $\frac{1}{4}$ inch in diameter and the entering pressure 70 pounds per square inch.

When the pressure is lowered by throttling, as the steam expands freely without doing external work, some of the heat contained in high pressure steam is liberated, and this quantity is utilized in evaporating any water that the steam may contain, and in raising the temperature of the steam above that due to its pressure, or, in other words, superheating it. When the steam contains much moisture, no heat may be left to superheat it after all or part of the moisture is evaporated, and, hence the calorimeter cannot be used. It is evident that the total heat of the steam before and after entering the calorimeter is the same, although there is a change in pressure.

We have already seen that the total heat in one pound of saturated steam of a quality Q is

$$H_1 = QL + S. \qquad (1)$$

The total heat of one pound of the superheated steam in the calorimeter, from what has been said above, must be equal to the sum of the heat, H′, in one pound of dry steam of the pressure in the calorimeter, and of that due to the superheating. This superheat will be represented by the number of units it takes to raise the temperature of the steam, from that due to the pressure in the calorimeter to that shown by the thermometer. The specific heat of steam being .48, and representing the temperature due to the pressure by t, and the observed temperature by T, we get the superheat, $.48(T - t)$, and for the total heat of the steam in the calorimeter,

$$H'' = H' + .48(T - t). \qquad (2)$$

Since the quantities in (1) and (2) are equal, we get

$$QL + S = H' + .48(T - t) \qquad (3)$$

from which

$$Q = \frac{H' - S + .48(T - t).}{L} \qquad (4)$$

The amount of moisture in the steam is $= 1 - Q$.

When the calorimeter exhausts at atmospheric pressure, as is usually the case, the normal temperature t, in the calorimeter, is

212° F., which corresponds to a pressure of 29.922 inches of mercury, or roughly, 30 inches, and then $H' = 1146.6$ units. But, for any other exhaust pressure, the temperature t must be that due to the manometer plus the barometer pressure. Suppose that the manometer reads 3 inches, or, $3 \div 2.04 = 1.47$ pounds, and the barometer reads 29.54 inches, or, 14.48 pounds. Then the pressure on the calorimeter is 15.95 pounds absolute, and the corresponding temperature $t = 216.4°$ F.

Example of Calorimeter Calculation.—From the log of the test, the following observations are obtained: Steam pressure by gage, 182 pounds per square inch; barometer, 29.54 inches; manometer, 10 inches; thermometer in calorimeter, 315° F.

The barometer reading, 29.54 inches, = 14.48 pounds.

Absolute steam pressure $= 182 + 14.48 = 196.48$ pounds.

Manometer reading, 10 inches $= 4.9$ pounds.

Absolute pressure in calorimeter $= 14.48 + 4.9 = 19.38$ pounds.

t = temperature corresponding to 19.38 pounds' pressure = 226.26.

T = temperature by thermometer in calorimeter = 315.00.

L = latent heat of steam of 196.48 pounds' pressure = 844.86.

S = sensible heat of steam of 196.48 pounds' pressure = 353.04.

H' = total heat of steam of 19.38 pounds' pressure = 1151.00.

Substituting these values in equation (4)

$$Q = \frac{1151 - 353.04 + .48(315 - 226.26)}{844.86} = .995,$$

or 99.5 per cent, and the moisture $= 100 - 99.5 = .5$ per cent, which is very small.

BARRUS' UNIVERSAL CALORIMETER.

This is shown in Fig. 128, the two parts being designated as the *heat gage* and the *separator.*

The heat gage consists of two chambers, shown by the dotted lines, which communicate with each other through a small hole in a diaphragm. This perforated plate is bolted between the flanges of the two chambers, with a gasket of non-conducting material on each side of it, to prevent the conduction of heat from one side to the other. Each chamber is provided with a thermometer cup. The whole heat gage is surrounded by a metal casing, the intervening space being filled with non-conducting material. Steam

from the main steam pipe enters the uper chamber first, and, in passing to the lower one, is throttled by the small hole, which is about $\frac{3}{32}$ inch in diameter. The outside of the separator and the covers of the heat gage are japanned; the cylindrical casing is nickel-plated. The instrument is small and easily portable.

The separator consists of a vertical chamber with an internal pipe running to near the bottom. The escape from the lower chamber of the heat gage is screwed into this internal pipe. The steam enters from above, passes down the internal pipe, then up around

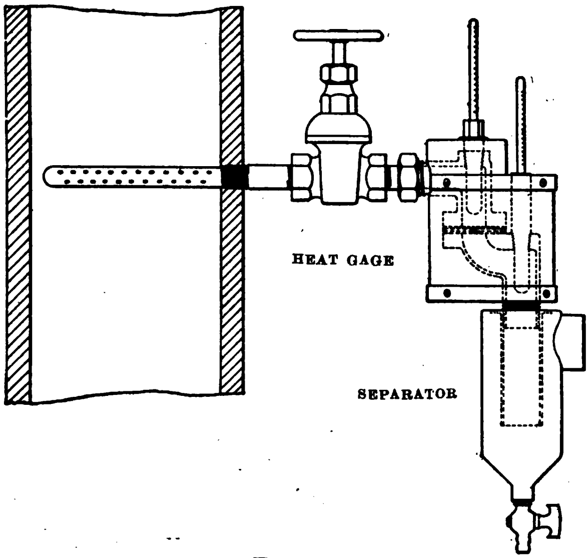


FIG. 128.

the outside of this pipe, and escapes to the atmosphere through the opening on the side and near the top of the separator. Any water that may be separated from the steam is collected at the bottom and drained off through a pet cock.

The manner of attaching this calorimeter and the precautions to be observed are the same as already described for the throttling calorimeter. The small hole must be kept clear. If blowing through does not clear the hole, disconnect the calorimeter, and clean the diaphragm and chamber of any particles of dust that may be there.

Using the Heat Gage Alone.—For good results, the readings for the two thermometers should be taken every five minutes, and the averages of these readings used in computing results. When the

boiler test is to be a long one, or, when the number of observers on the trial board is not large enough, the readings are taken every fifteen minutes and averaged.

For steam of quality 1 and Q, respectively, the total heat

$$H = L + S \tag{5}$$

and

$$H_1 = QL + S. \tag{6}$$

Suppose that steam of quality Q is allowed to run through the heat gage during the trial, and that the upper thermometer averaged t_1 degrees, and the lower one, T degrees Fahrenheit. After the trial, when fires are banked and little or no steam is passing through the main steam pipe, the steam formed in the boiler will, practically, be dry, or contain no moisture. If, under this condition, and keeping the temperature of the fire room as near the average observed during the trial, the steam pressure is maintained constant, as nearly as possible, at the point corresponding to the average temperature t_1, and the readings of the lower thermometer are noted during this time, we shall get a higher reading than T. This new temperature is called the normal reading of the lower thermometer. Since t_1 is the same for the boiler trial and for the test for the normal readings, the difference between t and T will be represented by the difference between (5) and (6), or by

$$H - H_1 = L - QL = L(1 - Q) = Lx,$$

x being the proportion of moisture, and L, the latent heat of steam at a pressure corresponding to t_1.

The superheating of the steam by throttling has already been explained, and we know that the heat represented by one degree of superheating is .48 unit. Mr. Barrus found, however, by experiment, that this quantity could not be applied exactly to this form of instrument, and that it varied somewhat according to the degree of moisture in the steam. For all readings of the lower thermometer above 235°, the quantity is taken as .42.

The cooling effect on the lower thermometer due to the moisture in the steam, or, the opposite of the superheating effect, is then equal to the heat difference, or,

$$Lx = .42(t - T)$$

and

$$x = \frac{.42(t - T)}{L} \tag{7}$$

from which $Q = 1 - x$ is obtained.

If the steam from the boiler is superheated before going into the calorimeter, .48 must be used instead of .42, and we have from (7)

$$Q = 1 - x = \frac{L - .48(t - T)}{L} = \frac{L + .48(T - t)}{L} \qquad (8)$$

Where T is the observed temperature by the lower thermometer, and t the normal temperature obtained by trial, as before.

Example.

t_1 = temperature by upper thermometer = 380.

T = temperature by lower thermometer = 280.

t = normal temperature corresponding to t_1 = 310.

L = latent heat at pressure corresponding to t_1 = 845.

$$x = \frac{.42(310 - 280)}{845} = .0149, \text{ or } 1.49\% \text{ moisture,}$$

and the quality of steam = .985.

Use of the Complete Instrument.—When the lower thermometer drops much below 214° F., the separator is brought into use, and the total percentage of moisture is divided into two parts. The first part is indicated by the heat gage, and is determined in the manner just described. The second part is the water which escapes to the separator and is there removed. This quantity is weighed, corrected for radiation, and then divided by the total quantity of steam and water which passes through the instrument in the same time, as found by experiment; the quotient multiplied by 100 gives the percentage of moisture discharged from the separator. It is determined, practically, in the following manner:

1. Collect the water, dripping from the bottom of the separator, in a pail resting on scales which are graduated to quarter ounces. Observe the weight every five minutes and continue the test for a period of at least half an hour. Find the weight of water collected during each five-minute interval, and reduce each one to its equivalent hourly rate by multiplying by 12.

2. Find the weight of water condensed per hour by radiation loss from the separator, and subtract this from the hourly weights just found. The remainders are the net quantities in the original steam which the heat gage fails to indicate.

The radiation loss may be found by blowing steam through the instrument (which must be done at some time when the boiler is making fairly dry steam) at such a slow rate that the lower thermometer indicates from 215° to 217°, then collecting and weighing

the water dripping from the separator, and calculating therefrom the hourly loss. This loss amounts to approximately 0.13 of a pound per hour when the surrounding temperature is 70.°

3. Divide the net quantities found in par. 2 by the quantity of steam and water passing through the calorimeter per hour. The results, multiplied by 100, give the percentages of moisture shown by the separator, and corresponding to the successive five-minute observations. Find the average of these percentages.

4. Add this percentage to that computed from the heat gage readings; the sum is the total percentage of moisture in the steam.

5. To find the quantity of steam and water passing through the instrument, attach a pipe to the side outlet and a rubber tube to the bottom nipple, and carry both to a tub of water resting on scales. Find the increase in weight for a period of say five minutes, and multiply this by 12 to obtain the rate per hour. For approximate work, the quantity in pounds per hour can be determined from the following formula,

$$\text{Quantity} = \frac{\text{Pressure above zero} \times \text{area} \times 3600}{70}$$

Where the pressure is that of the steam corresponding to the temperature shown by the upper thermometer, and the area is that of the small orifice.

Example.

t_1 = temperature by upper thermometer = 380.

T = temperature by lower thermometer = 213.

t = normal temperature corresponding to t_1 = 310.

x = moisture shown by heat gage, in per cent = 4.82.

Water from separator, per hour, pounds = 2.5.

Loss by radiation from separator, per hour, pound = .14.

Water from separator, per hour, corrected for radiation, pounds, = 2.36.

Total quantity of steam and water passing through instrument, per hour, pounds = 43.

Percentage of moisture shown by separator, $2.36 \times 100 \div 43 = 5.49$.

Total percentage of moisture in steam, $4.82 + 5.49 = 10.31$.

Quality of steam = .8969.

17. *Calculations of Boiler Efficiency.*—There are two methods of defining this efficiency:

1. Efficiency of the boiler $=$

$$\frac{\text{Heat absorbed per pound of combustible}}{\text{Calorific value of one pound of combustible.}}$$

2. Efficiency of the boiler and furnace $=$

$$\frac{\text{Heat absorbed per pound of coal}}{\text{Calorific value of one pound of coal.}}$$

The first is the efficiency based on the combustible and is the best for comparison of tests. The second is based on dry coal, and should be given, so that different furnaces, grates, fuels, or methods of firing and of supplying the air can be compared.

The method of calculating the above efficiencies will be clearly understood from the blank forms of the "Report on Evaporative Tests," given at the end of this chapter, but a short review of the various steps which lead up to the final result may be useful. For this purpose, the second efficiency will be taken, using percentages instead of proportional parts.

The denominator of the efficiency fraction is found by means of the coal calorimeter, or from the ultimate chemical analysis. To find the numerator, we must go back to the log of the boiler test and get the weight of the coal burned, corrected for moisture, and that of the water fed to the boiler and its temperature. To obtain the number of heat units absorbed by one pound of steam of the quality found by the calorimetric test, we proceed as explained in Chapter III; to express this number in terms of one pound of dry coal, it is multiplied by the number of pounds of water fed to the boiler, and divided by the total weight of dry coal burned during the same time. The number so obtained will be the required numerator. If this quantity is desired in terms of combustible, the weight of combustible burned must be used instead of that of coal.

In order to state the economic results of the trial in terms of water from and at 212° F., per pound of coal and combustible, as required in all reports of trials, they can be found directly by dividing the number of heat units, as just found, by 965.8. But, if the method given in pars. 49 to 52 of form No. 104-5 is employed, then Q, as found from the calorimetric tests, must be corrected. For, as given there, the total weight of water W, fed to the boiler, multiplied by Q is taken as the actual weight of water evaporated into dry steam. This actual weight, multiplied by the factor of evaporation f, then gives the equivalent weight of water evaporated from and at 212° F., or

$$W' = WQf \tag{9}$$

But, in using Q in this way, it is assumed that only the Q parts of water evaporated were raised from the temperature of the feed to that corresponding to the steam pressure, the heat required to raise the $1 - Q$ parts being neglected. This is shown by referring to Chapter VII, where the total heat required to generate one pound of wet steam of quality Q is

$$H_1 = QL + S - S'. \tag{10}$$

For W pounds, the total number of heat units required would be $W(QL + S - S')$, and the correct equivalent weight of water evaporated is, therefore,

$$W' = \frac{W(QL + S - S')}{965.8}. \tag{11}$$

By substituting the value of f in equation 9, we get

$$W' = WQ \times \frac{L + S - S'}{965.8} \tag{12}$$

which should be, but, as is evident, is not equal to the correct value of W' in equation 11; it is equal only when $Q = 1$. To make equation 12 applicable to all degrees of moisture, we must refer to equation 10 and put it in its original form, from which we see that the total heat of one pound of the mixture is $Q(H - S') + (1 - Q)(S - S')$. This, in terms of the heat units received when one pound of water is evaporated to dry steam, is

$$\frac{Q(H - S') + (1 - Q)(S - S')}{H - S'} = Q(1 - Q)\left(\frac{S - S'}{H - S'}\right) = F. \tag{13}$$

This is called the "factor of correction for the quality of steam" by Mr. C. E. Emery, who first drew attention to this correction. It is to be substituted for the value of Q in equation 9, which then becomes,

$$W' = WQf = W\left\{Q + (1 - Q)\left(\frac{S - S'}{H - S'}\right)\right\} \times \frac{H - S'}{965.8} =$$
$$\frac{W\{Q(H - S') + (1 - Q)(S - S')\}}{965.8}. \tag{14}$$

But, as tables of factors of evaporations are usually made out for increments of 10 pounds in the steam pressure and 10 degrees in the temperature of the feed water, it will be found that, by the time that the proper factor of evaporation has been obtained by calculation, and Q corrected, by substituting its factor of correction, the method of heat units as given by equation 11 is much shorter.

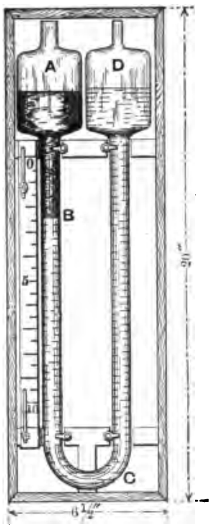
The equivalent evaporation from and at 212° F. per pound of coal as fired, per pound of dry coal and per pound of combustible, can then be found by dividing W′, in equation 14, by the total weights of coal, dry coal and combustible, respectively. To obtain these quantities in terms of heat units, each is multiplied by 965.8. The same results are, of course, obtained by dividing the numerator of (14) by the pounds of coal or combustible.

For superheated steam, where Q is greater than unity (if the method of heat units is employed), we use the equation of the total heat of one pound of this steam, as given in Chapter VII,

$$H'' = H + .48(T - t).$$

But, if Q is used as in equation 9, the proper factor F must be substituted for Q. Since the superheating of each pound of steam will require .48(T — t) heat units, T being the temperature of the superheated steam, and t the temperature of the dry saturated steam of the same pressure, the factor will then be,

$$F = \frac{H - S' + .48(T - t)}{H - S'} = 1 + \frac{.48(T - t)}{H - S'} \qquad (15)$$



BARRUS DRAFT GAGE
FIG. 129.

The following instruments and apparatus, not previously described, are necessary for a boiler test.

Barrus Draft Gage.—The ordinary air pressure or draft gage, described in Chapter VI, lacks sensitiveness when measuring small quantities. The Barrus gage, Fig. 129, multiplies the indication of the ordinary U-tube by the use of two liquids of slightly different specific gravities, such as alcohol (colored red for ready observation) and a certain grade of petroleum oil.

This instrument consists of a tube, usually made of ½-inch glass, which is surmounted by two glass chambers having a diameter of about 2½ inches, and arranged as shown.

It is placed in a wooden case provided with a cover, and secured in an upright position. Of the two liquids, which will not mix and which are of different colors, one occupies the portion A-B, and the other, which is the heavier, the portion B-C-D. When the right-hand tube is connected

to the uptake or smoke pipe, the suction produced by the draft draws the line of demarkation B downward. The amount of this motion is proportional to the difference in the areas of the two chambers and of the U-tube, modified somewhat by the difference in the specific gravities of the liquids. By referring to the scale on the side, the amount of motion is measured in inches. This scale is movable, and can be adjusted to the zero point by loosening the thumb screws. A multiplication varying from 8 to 10 times is obtained in the instrument shown; in other words, with ¼-inch of draft, the movement of the line of demarkation is from 2 to 2½ inches, the exact amount of multiplication having been determined by calibration referred to a standard instrument.

Brown's Quick-Reading Pyrometer.—This instrument depends on the expansion of a strip of platinum secured in an iron pipe frame. By suitable rods and levers, the expansion causes the pointer of a standardized gage to indicate the temperature. When the iron frame becomes heated, the motion of the pointer will be reversed, and the instrument must then be withdrawn immediately and allowed to cool before the next reading is taken. The reading is taken at the instant of reversal of the pointer. It will take from fifteen to twenty seconds to indicate a temperature up to 2000 and 3000° F., and about twenty minutes to cool.

Le Chatelier's Pyrometer.—This is, probably, the most reliable instrument for measuring high temperatures. It consists of a thermo-element composed of a platinum wire and another of an alloy of platinum and rhodium. The wires are insulated by a thin porcelain tube, and the junction is protected from the gases by a larger, closed porcelain tube. The current of electricity, generated by exposing the junction to heat, is measured by a suitable galvanometer, which has a carefully calibrated temperature scale besides the voltage scale. The junction of the thermo-couple is in the form of a small ball or button.

Fig. 130 shows an improved form of this instrument devised by the Vulcan Manufacturing Company of Pittsburg.[1] This form was designed for use in ascertaining the temperatures of molten metal, for which purpose the porcelain tubes would not answer. Even with the ordinary measurements of the gases of combustion, the

[1] From a paper on "The Melting Point of Cast Iron," by Dr. R. Moldenke, reprinted in the Journal of the American Society of Naval Engineers, Vol. X.

porcelain tubes have to be handled with great care to prevent breaking.

An iron tube, through which run the wires of the couple, has a connection at one end for the clay tip which protects the junction, and, at the other end, a terminal box for the copper wire connections to the galvanometer. The wires are covered with asbestos for insulation from each other and from the iron pipe, and are covered by an asbestos tube where they pass through the fire clay tip. The connection for this tip is interchangeable, so that the tip may be secured at an angle, as in the figure, or straight. The rest of the instrument is fully explained by the figure.

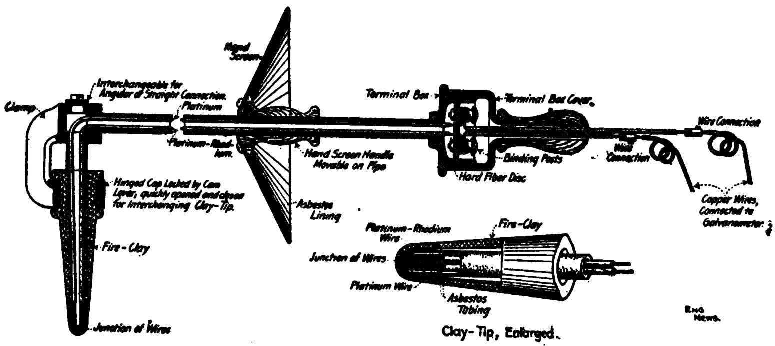


FIG. 130.

The galvanometer used is a D'Arsonval, specially made and calibrated for industrial purposes, the original form, with a reflecting mirror and capable of registering to one-half degree, being too cumbersome and delicate. The sensitiveness of the couple, even when protected by a refractory material, is such that, when it is plunged cold into the melted iron, the reading is obtained in one and three-fourths minutes. When it is heated to redness beforehand, this time is reduced to a few seconds.

BLANK FORMS FOR BOILER TESTS.

S. E. Form No. 104-1.

DATA AND RESULTS OF EVAPORATIVE TEST.

Made by ....

of .... boiler, at ....

to determine ....

Principal conditions governing test...................................

S. E. Form No. 104-2.

DESCRIPTION AND DIMENSIONS OF BOILER AND APPURTENANCES.

Type of boiler...

Diameter of shell, ...; top drum, ... bottom drum, ...

Length of shell, ...; top drum, ...; bottom drum, ...;

Tubes, number,....; diameter, outside,....; length,.... thickness,....

Furnace, kind of, ...

Furnace, length, ...; width, ...; height, ...

Grate surface, length, ...; width, ...; area, ...

Heating surface, area, ...; ratio to grate, ...

Per cent water heating surface,....; per cent superheating surface,....

Grate bars, kind, ...

Grate bars, width of air spaces,....; ratio of grate to air space,....

Smoke pipe, area, ...; height, ...; ratio to grate, ...

Water space, ...; steam space, ...

Weight of boiler and all fittings except uptakes and smoke pipe:

Without water, ...

Water, ...

Total with water, ...

Total weight per square foot of grate surface........................

Total weight per square foot of heating surface......................

Blower engines, kind, ...; Dimensions cylinders, ...x....x....

Blower fan, kind, ...; diameter, ...; width, ...

Area of blower inlet.....................; outlet.....................

Feed heater, kind...

Feed heater, area of surface..

Economizer, kind ....

Area of surface...

Air heater, kind..

Area of surface...

Feed pumps, kind.............; dimensions of cylinders....x....x....

Other boiler appurtenances..

S. E. Form No. 104-3.

DESCRIPTION OF APPARATUS.

a. Method of weighing water..

b. Method of weighing fuel...

c. Method of determining the amount of moisture in steam.

Kind of calorimeter used...

Distance of calorimeter from boiler..............................

Size, shape, and description of sampling nozzle..................

d. Method of taking temperature of and sampling flue gases......

e. Condition of boiler before and after test......................

S. E. Form No. 104-4.

Number of test..

1. Date of test..
2. Duration of test................hrs..........................
3. Kind of fuel..
4. Kind of start..
5. State of weather..

Average Pressures.

6. Barometer ....ins..........................
7. Steam pressure by gage........lbs............................
8. Force of draft at base of pipe...ins. of water....................
9. Force of draft in furnace........do............................
10. Force of draft in ash pit.........do............................
11. Revolutions of blower..

Average Temperatures.

12. External air ....degrees F..........................
13. Fire room.......................do..........................
14. Steam ....do............................
15. Feed water entering heater........do............................
16. Feed water entering economizer....do............................
17. Feed water entering boiler.........do............................
18. Air entering ash pit...............do............................
19. Escaping gases from boiler.......do............................
20. Escaping gases from economizer....do............................

Fuel.

21. Kind of ....
22. Weight of wood used in lighting fires......lbs....................
23. Weight of coal as fired[1]................. ..lbs....... ....
24. Moisture in coal.....................per cent....................
25. Weight of dry coal consumed..............lbs....................
26. Weight of ash and refuse.................lbs....................
27. Weight of combustible consumed..........lbs....................
28. Per cent of refuse in dry coal..

Fuel per hour.

29. Coal consumed per hour..................lbs....................
30. Dry coal consumed per hour..............lbs....................
31. Combustible consumed per hour.........lbs....................
32. Coal consumed per hour per sq. ft. G. S...lbs..................

[1] Including equivalent of wood used in lighting fires.

33. Dry coal consumed per hour per sq. ft. G. S. . lbs....................
34. Combustible consumed per hour per sq. ft.
G. S. ....lbs....................

S. E. Form No. 104-5.
Number of Test..
35. Coal per hour per sq. ft. H. S...............lbs....................
36. Dry coal per hour per sq. ft. H. S..........lbs....................
37. Combustible per hour per sq. ft. H. S.......lbs....................

Quality of Steam.

38. Per cent of moisture in steam..............................
39. Degrees of superheating....................................
40. Quality of steam (dry steam = 100)..........................

Water.

41. Total weight of water fed to boiler[2]......lbs....................
42. Water actually evaporated, corrected for
quality of steam (40 by 41).............lbs....................
43. Factor of evaporation......................................
44. Equivalent water evaporated into dry steam
from and at 212° (42 by 43)............lbs....................

Water per Hour.

45. Water evaporated per hour, corrected for
quality of steam........................lbs....................
46. Equivalent evaporation from and at 212°..........................
47. Equivalent evaporation from and at 212° per
sq. ft. G. S............................lbs....................
48. Same per sq. ft. of heating surface.........lbs....................

Economic Results.

49. Water apparently evaporated under actual
conditions per lb. of coal as fired (41÷
23) ....lbs....................
50. Apparent equivalent evaporation from and
at 212° per lb. of coal including moisture
(44÷23).................................lbs....................
51. Equivalent evaporation from and at 212° per
lb. of dry coal (44÷25).................lbs....................
52. Equivalent evaporation from and at 212°
per lb. of combustible (44÷27)..........lbs....................

[2] Corrected for inequality of water level and steam pressure at beginning and end of test.

Efficiency.

53. Efficiency of boiler; heat absorbed by the boiler per lb. of combustible divided by the heat value of one lb. of combustible. (*See* Form No. 6) ....

54. Efficiency of boiler, including grate; heat absorbed by the boiler per lb. of dry coal, divided by the heat value of one lb. of dry coal. (*See* Form No. 6) ....

Remarks and Observations.

55. Principal data taken every ....
56. Percentage of smoke as observed ....
57. Method of observing same ....
58. Kind of firing (spreading, alternate, or coking) ....
59. Average thickness of fires ....
60. Average intervals between firings for each furnace during fires were in normal condition ....
61. Average interval between times of breaking up ....
62. Efficiency of firemen; expert, average, or poor ....

S. E. Form No. 104-6.

FUEL AND GAS ANALYSES.

PROXIMATE ANALYSIS OF FUEL.

	Coal. *Per cent.*	Combustible. *Per cent.*
Fixed carbon	....	....
Volatile matter	....	....
Moisture	....	....
Ash	....	....
Total	100.00	100.00
Sulphur separately determined	....	....

ULTIMATE ANALYSIS OF DRY FUEL.

	Coal. Per cent.	Combustible. Per cent.
Carbon (C)	....	....
Hydrogen (H)	....	....
Oxygen (O)	....	....
Nitrogen (N)	....	....
Sulphur (S)	....	....
Ash	....	....
	100.00	100.00
Moisture in sample of fuel as received	....	....

ANALYSIS OF ASH AND REFUSE.

	Per cent.
Carbon	....
Earthy matter	....

CALORIFIC VALUE OF FUEL.

Kind of Calorimeter used..

Calorific value by calorimeter, per pound of dry coal...........B. T. U.

Calorific value by calorimeter, per pound of combustible........ Do.

Calorific value by analysis, per pound of dry coal.............. Do.

Calorific value by analysis, per pound of combustible........... Do.

ANALYSES OF DRY GASES.

	Per cent.
Carbon dioxide (CO_2)	....
Oxygen (O)	....
Carbon monoxide (CO)	....
Hydrogen and hydrocarbons	....
Nitrogen (N) (by difference)	....
	100.00

APPENDIX.

EXTRACT FROM U. S. NAVY REGULATIONS.

SECTION 2.—CARE OF ENGINES AND BOILERS.

1606. (1) The cylinders, receivers and steam jackets must be gradually and thoroughly heated by opening connections between the boilers and engines, as soon as the fires are lighted and before steam of full pressure is admitted to them. The greatest care must be exercised that "water rams" are guarded against by carefully draining all pipes while raising steam.

(2) Water must not be allowed to accumulate in the jackets or receivers, but care shall be taken that steam is not being blown through the traps.

(3) Every opportunity shall be used to ascertain the proper grades of expansion in each cylinder for different powers; the powers developed in each cylinder should be equal, or nearly so, and, when the proper points are ascertained, a careful record must be made in the senior engineer's remark book for reference when changes in speed or power are required.

(4) The indicators shall not be allowed to remain attached to the cylinder when not wanted for immediate use; and they shall be dried, cleaned, and lightly lubricated with cylinder oil before being put away.

(5) No tallow nor oil of vegetable or animal origin shall be used for the lubrication of cylinders and valves, but mineral oil only shall be employed.

(6) As little oil as possible shall be used for interior lubrication; this prohibition is intended to apply to every steam cylinder in the ship, for whatever purpose intended.

(7) Care must be taken that the oil used for lubricating the rods is not drawn into cylinders in which there may be a partial vacuum.

(8) The cylinders, piston rings, piston springs, followers, and follower bolts shall be frequently examined and their condition noted in the steam log.

(9) All cocks and valves throughout the engineer department are to be moved at least once each week.

(10) When not under steam, the engines and main valves are to be moved every day, when possible, and all steam machinery jacked at frequent intervals, the fact being noted in the steam log.

(11) Zinc plates shall be suspended in the hot wells and condensers to prevent corrosive action. The condition of the zinc and of the interior surfaces shall be frequently examined and noted in the steam log.

(12) All holding-down bolts shall be examined at least once in three months, and care taken that the nuts of pillow-block bolts do not become set fast. The clutch couplings shall be moved and lubricated once a day when not under steam.

(13) The gratings over the engine room hatches are not to be taken off, except in cases of necessity, and shall be replaced as soon as possible.

(14) The instruments fitted on board for telegraphing signals to and from the engineer department shall be carefully examined, oiled, and tried before getting under way.

(15) Mineral oil causes rubber valves to swell and overlap each other. All such valves must be examined periodically, turned and trimmed to their original size, if necessary. Their condition as well as that of the condensers, at each examination, shall be noted in the steam log, with all further information that may be considered necessary. Rubber valves will be washed in a solution of soda and potash.

(16) As soon as practicable after each run, the manhole plates on cylinder heads will be removed and the interior of cylinders cleaned and covered with a thin coating of oil or vaseline.

1607. (1) Water should not be used unnecessarily on the bearings; and when it is used, care will be taken that it is discontinued a sufficient length of time before the engines are stopped to allow the lubricating oil to find its way to all parts of the surface of the journals.

(2) When water has been used on a bearing, the bearing shall be examined at the earliest opportunity.

1608. (1) The tubes of surface condensers must be examined at least once in six months and kept clean. If not examined, the reasons for the omission are to be stated in the quarterly report. If any considerable amount of steaming has been done, the condensers must be examined before the expiration of the time mentioned.

(2) If at any time the condenser tubes are found to be leaking, steps will be taken, as soon as the engines are stopped, to prevent the passage of water from the condensers to the cylinders.

(3) Valves of sounding pipes to double bottoms must be kept closed when not in use. The height of the water in the bilges will be measured and all bilge and crank-pit strainers cleaned each watch.

(4) Independent air and circulating pumps will be started at least fifteen minutes before attempting to move the engines, or to warm the cylinders by means of the pass-over valves.

(5) When filters or grease extractors are fitted, they must be used, except when under repairs or being cleaned.

(6) The valves of air and circulating pumps shall be examined frequently.

(7) The boiler feed pumps shall not be used for other purposes than those connected with their special service, except in cases of emergency; and, when not under steam, their pistons and valve gear must be moved every day and the cylinders kept well oiled.

(8) The interiors of evaporators shall be frequently examined and the tubes or coils cleaned and scaled when necessary.

(9) When evaporator tubes or coils are made of iron or steel, zinc plates shall be fitted for protectors, as in boilers.

(10) When an evaporator will not be required for use for several days, the shell and coils shall be drained and kept dry till needed for service.

1609. (1) Special mention shall be made in the quarterly reports of the condition of the boilers and the means which have been employed for their preservation.

(2) Zinc slabs shall be suspended in such parts of the boilers as may be directed by the Bureau of Steam Engineering. The senior engineer officer on each inspection of the boilers shall examine these zincs and note their condition in the log. To make the zincs efficacious, special care must be taken to insure perfect metallic contact between the zincs and the stays or plates of the boilers to which they are attached, the surfaces in contact being filed bright.

(3) Slabs of rolled zinc will be used, these being renewed as soon as the exposed surface is reduced by oxidation to about half the original area. Zincs that have become bent or distorted should, however, be removed at once as inefficient. Worn and defective zincs will not be recast for use on board. Should it be necessary

to use slabs of cast zinc at any time, good material only shall be used.

(4) It has been found by experience that the number of zinc slabs (twelve by six by one inch) required for the thorough preservation of boilers is about one for every fifty square feet of tube surface; that is, approximately equal to $\frac{N \times D \times L}{197}$, where N is the number of tubes plus the number of solid stays fitted in lieu of stay tubes, L the length between tubes plates in feet, and D the external diameter of tube in inches. When the number has not otherwise been determined by the Bureau of Steam Engineering, this will be the proportion used. This proportion is, however, merely intended as a guide, and not to interfere with any alteration of position or number which may appear desirable or necessary for the arrest of oxidation. About one-sixth of the whole number of slabs should be put in the steam spaces.

(5) No tallow nor oil of vegetable or animal origin shall be allowed to enter the boilers. This prohibition applies to all boilers in use aboard ship of whatever type or service.

(6) The dry pipes and drains of the steam drums are to be examined frequently to ascertain if the holes in them are clear.

(7) The boilers, when empty, are to be kept dry by such means as are at the disposal of the officer in charge. The water bottoms and lower parts of the fronts are to be kept free from scale and rust and contact with ashes, and well painted.

(8) Boilers that are not in use should be kept, if possible, full of fresh water made slightly alkaline, and failing this, full of salt water made slightly alkaline. (See par. 22.)

(9) When water is used from a shell boiler, the water line must not be maintained at a level among the tubes.

(10) When boilers are empty the furnaces shall not be primed.

(11) The main and auxiliary stop valves, safety, check and blow valves, and any other valve or cock by which steam or hot water could enter the boilers in which men are at work, will be shut and secured so that they cannot accidentally open or be opened. The engineer officer having the day's duty will see that these precautions are carried out before he allows any men to enter the boilers.

(12) The safety valves will be partially lifted by the hand gear at least once each week when not under steam, to insure their good working order.

(13) The boilers will always be filled with fresh water when possible. When filled from overboard, the necessity for doing so from shallow water or using impure water of any kind should, as far as possible, be avoided.

(14) The water will be retained in the boilers without change as long as possible, even when the fires are not lighted. The boiler will be drained only when necessary for examination, cleaning, or repairs, and the water changed only when dirty or acid, or when the boiler is to be used for distilling without the aid of an evaporator.

(15) The boilers shall not be used for trimming ship nor for water tanks for any purpose except for a reserve of fresh water when steaming in free route. Salt water shall never be introduced into the boilers except for the purpose of washing out the interiors, or to make up a deficiency of feed when steaming, when the supply of fresh water is not sufficient, or as permitted in paragraph 8 of this article. When the interior of a boiler has been washed out with salt water, it shall be filled with fresh water immediately thereafter, or if fresh water is unobtainable, with salt water.

(16) The exteriors are to be kept as dry as possible and nothing wet or combustible is to be stowed over or around them. The bilges in the fire rooms are to be kept dry and well painted.

(17) Sudden changes of temperature in the boilers are to be avoided; and when circumstances will permit, at least six hours should be occupied in raising steam from cold water.

(18) Connection doors must not be used as dampers.

(19) The uptakes shall be kept free from dirt and well painted.

(20) The number of hours each boiler has had fires under it since the ship was commissioned is to be stated in each quarterly report.

(21) Fires shall not be hauled after discontinuing steaming, except in case of emergency, but shall be allowed to burn down and die out in the furnaces, with the dampers, furnaces, and ash pits closed. The boilers shall not be blown down; when it is required to empty them, the water shall be pumped out.

(22) When coil, pipe, or water-tube boilers are not in use for steaming purposes, their interiors shall, if possible, be kept perfectly dry; their exteriors shall also be kept dry and, where accessible, well painted with metallic paint.

(23) If for any cause, such as a leaky valve, it is impossible to keep the interiors of coil, pipe, or water-tube boilers perfectly dry

when not in use for steaming purposes, boilers of this class shall, till such cause can be removed, or the boilers are required for steaming purposes, be kept filled to their highest point with fresh water made slightly alkaline.

(24) Light fires shall occasionally be made in drying stoves placed in the ash pits of coil, pipe, or water-tube boilers not in use, in order to dispel moisture.

(25) Coil, pipe, or water-tube boilers shall never be used as tanks or reservoirs for any purpose whatever.

(26) Forced draft shall not be used on cylindrical fire-tube boilers except in emergencies and during the power trials specified in article 1603.

(27) When it is necessary to increase the speed of a vessel having cylindrical fire-tube boilers it shall be done (except in case of emergency) by increasing the number of boilers in use, under natural draft, until the entire number on board is in use, if requisite.

(28) The blowers may be run at any time at moderate speed, for purposes of ventilation or to assist the draft, but the air pressure must not exceed one-half inch of water.

(29) The temperature of the feed water at the feed pumps will be as nearly as possible that of the water in the boilers. Where no special heaters are fitted, the temperature will be as high as is consistent with the maintenance of a fair vacuum.

(30) The air space between the uptake and casings of the boilers shall be examined frequently, and any accumulation of soot or coal dust prevented.

(31) As in ordinary cruising it is usually necessary to use only part of the boilers, the work will be distributed equally among the different boilers. If any peculiarity of fitting or other cause prevents this distribution, the fact must be stated in the quarterly report of the log.

(32) When it is necessary to keep ashes in the fire rooms until a lighter can be obtained, they must not be stowed against any part of the boilers or bulkheads; boards or heavy canvas must be used to protect the metal surfaces.

(33) Coal must not be stowed in the fire rooms in such quantities as to cover up the handles or wheels of valves, or to get into the bilges, thus choking up suctions and strainers and endangering the safety of the ship.

(34) The thin sheet-iron bulkheads or air ducts of the forced

draft system must be kept free from ashes and rust and well painted.

1610. (1) In order to determine the condition of the water in the boilers as regards its acidity, neutrality, or alkalinity, the water in each boiler will be tested with both kinds of litmus paper at least once per day when they are under steam, and once per week when the fires are not lighted.

(2) If the water in the boilers, on applying litmus paper, be in an acid condition, a small quantity of soda will be put into the condensers or hot wells, from which it will be pumped into the boilers with the feed water. If the water in any one boiler shows acid properties, a solution of soda will be injected into that boiler. Only the smallest quantity of soda possible to accomplish the purpose intended shall be used.

1611. Heavy banked fires should never be kept except in cases of emergency, but when so banked ash pan doors shall not be put in place.

1612. (1) The boilers of all vessels in commission shall be tested by water pressure at such times as the senior engineer officer may deem necessary or advisable.

(2) The test water pressure applied to boilers shall not exceed the designed working pressure plus twenty-five per cent of same when the boilers have been in service longer than two years.

(3) During the application of water pressure, the boilers will be carefully examined and proper gages used to detect any change in the form of any of their parts.

(4) In applying water pressure care must be taken that there is no leak past the main or auxiliary stop valves.

(5) Should a drill test (Art. 1615) be made and reveal unusual thinness of any plates, the water pressure will be very carefully applied, in order that injury may not be caused by overpressure.

1613. The following particulars of the results of boiler tests will be entered in the steam log and the senior engineer officer's remark book: The greatest pressure applied; the load per square inch on safety valves previous to the test and when boilers were first used; the date of last repair; the length of service for which the boilers were repaired; the effect of the test on the plates and stays of furnaces, combustion chambers, and shell, and on the tube sheets; the estimated durability of the boilers with such repairs as can be made by the force on board; and such additional information as may be

considered necessary to enable a more complete estimate to be formed of the condition of the boilers.

1614. (1) The boilers will be thoroughly examined at regular intervals of about three months; other examinations being made as opportunity offers and as the senior engineer officer may consider necessary. A detailed description of the condition of each boiler at each of these examinations shall be entered in the steam log and the senior engineer officer's remark book.

(2) If any thing should occur to prevent these periodical examinations, the cause will be fully stated in the steam log.

1615. When, during the periodical examination of boilers, the senior engineer officer has reason to believe that any part or parts of the boiler are unduly worn or corroded, he will cause these parts to be tested by drilling, the holes to be not over one-half inch in diameter. The thickness of the plates originally and when drill-tested, the probable cause of corrosion or wear, and all other details of the test will be entered in the steam log and senior engineer officer's remark book.

1616. Full information will be noted in the steam log of the kind, quality, steaming power, and other particulars of the coal received. The statement that the coal is bituminous or anthracite being indefinite, will not be used except when it is impossible to obtain any further information of the coal received, in which case a special note of the fact will be entered in the steam log.

1617. (1) All paint work about the engineer department shall, if practicable, be white.

(2) Should red lead be used at any time for painting the double bottoms or other confined spaces in the engineer department, the senior engineer officer will see that proper precautions are taken to prevent its injurious effects on the health of the men. Two days is the maximum length of time that a man should be kept at this work.

1618. Cotton waste or any other materials used for wiping, and which are saturated with oil, will be destroyed immediately after using, or, if intended for starting fires, will be put in a covered iron receptacle, and the latter kept in a safe place.

1619. (1) All chocks and ties fitted to cylinders, boilers, and other parts of the machinery, to prevent their shifting from the effects of collision, will be kept at all times in an efficient condition, and they will be examined at least once each quarter and their condition noted in the steam log.

(2) Before going into action, all articles which might be thrown down or displaced by a collision will be secured, or so disposed that no injury can be done to the machinery or to the officers and men in the engineer department.

(3) When it is intended to ram, or when the vessel is likely to be rammed, notice will be given from deck to the engineer officer of the watch, through the speaking tube or by other prompt method of signaling, so that men, tools, etc., may not be thrown down or against moving parts of the machinery.

(4) To prevent the passage of water from the boilers into the engines when the collision takes place, the separator will be emptied and its blow-off cock opened to the sea just before the shock is expected to take place. This cock may also be allowed to remain open until the engines are safely reversed.

(5) A man will be stationed at each of the main stop valves to shut off any or all of the boilers should it become necessary, and in order to facilitate this, the valves will be screwed down as far as possible without reducing the steam required by the engines.

(6) In ramming, being rammed, and generally in cases of collision, the men should go to their stations for starting all bilge pumps, bilge injectors, and other means provided for freeing the ship of water in case of dangerous leakage.

1620. (1) The preceding instructions for the management, care, and preservation of the machinery of the vessel will, as far as applicable, govern the management, care, and preservation of the machinery of the steamboats.

(2) The safety valves of the boilers of steamboats will be examined whenever steam is raised after an interval of more than seven days not under steam. The condition of the safety valves, water gages, check valves, etc., will be ascertained from time to time while the machinery is working. Great care will be taken to keep these important fittings in a thoroughly efficient condition.

(3) Salt water will not be used in the boilers of steamboats except in cases of great emergency, and after its use the boilers will be scaled and cleaned as soon as possible.

(4) The time that steamboats have been under steam will be entered in the steam log.

(5) Under no circumstances will the height of water in locomotive boilers be less than three inches over the crown sheets.

(6) Unless it is expected that the machinery of steamboats will be used again in a few days, the wearing surfaces of cylinders and valve chest will be cleaned and lightly coated with mineral oil, and the engines made ready for use. All drain cocks should be kept open and the engines, valves, pumps, etc., moved every day.

(7) Strainers on sea-valve openings of steamboats will be kept clear, and receiving pipes of circulating and air pumps examined and cleaned annually, or more frequently, if necessary.

(8) The boilers of steamboats will be frequently examined, internally and externally. Especial attention will be paid to the furnace.

(9) In boilers fitted with removable stays or braces, great care will be taken to replace them properly when they have been taken out. The boiler will be tested by hydraulic pressure after the stays have been replaced. The reasons for removing the stays and the result of the test will be entered in the steam log.

1621. (1) In consequence of the lightness of construction and the high speeds at which torpedo boat engines run, increased care is necessary in attending to and adjusting the various working parts. Mineral oil only will be used in the cylinders, and that sparingly and only at high speeds, as no lubricant is, as a rule, necessary at moderate speeds. Oil will not be put into the cylinders when it is probable that the engines will soon be stopped.

(2) Vedette torpedo boats may continue to run at moderate speed for at least thirty days without changing the water in the boiler. Should, however, a long run at high speed be anticipated, the boiler will be washed out and refilled before starting. With new boilers, it may be necessary to change water several times until they are quite clean.

(3) Vedette torpedo boats will be run for three hours for the purpose of instruction of the men, once in each quarter.

1622. (1) After using air-compressing machinery, great care will be taken to see that the engines, pumps, separators, charging columns and reservoirs are blown out and well drained.

(2) A spare set of cup washers will always be kept ready for immediate use.

(3) All parts of the machinery subject to pressure will be tested to the full pressure once each year and the fact noted in the steam log.

(4) The oil for lubricating the internal parts will be neatsfoot when the cups are of leather, or, if that cannot be obtained, other animal oils or castor oil will be used.

(5) Cup leather washers must be kept in tins filled with castor oil.

(6) Distilled water should be used for lubricating the internal parts of the pumps, if it can be obtained; water containing lime must not be used.

(7) Owing to the small clearances allowed in air-compressor pumps, great care must be used in adjusting the bearings.

1623. (1) The hydraulic pumps, engines, pipes, and the gear connected therewith will frequently be examined, kept in good order and clear of water when not being worked.

(2) The hydraulic engines will be moved at least twice a month by means of the pumps fitted for the purpose, to prevent the rams becoming set and to insure their efficiency.

(3) When water must necessarily remain in the pipes, the air cocks will be left open; stoves will be used if there is any danger of freezing.

1624. (1) When a ship is ordered out of commission, the iron or steel bright work of the machinery, except such parts as pass through stuffing boxes, or upon sliding surfaces (as piston rods, valve stems, slide and guide faces and journals), shall be covered with white lead and tallow.

(2) Packing shall not be removed from piston rods or valve stems.

(3) All parts passing through stuffing boxes or working upon their surfaces, such as piston rods, valve stems, guide and slide faces, clutch coupling slides, interiors of steam cylinders and valve chests, must be cleaned and covered with a coating of vaseline, the machinery being moved after first application so as to bring all these parts upon properly covered surfaces.

(4) All bearings must be well oiled and the oil holes plugged with waste, the engines being turned one complete revolution after oiling.

(5) All water-containing parts of the machinery inside of outboard valves shall be thoroughly drained. Particular attention should be paid to draining of pump cylinders; condensers; feed, blow, and suction pipes; fire main, and all steam and exhaust piping where it is possible for water to gather. In draining these pipes,

flange joints should be broken at the lowest parts of each system and wherever a pocket is formed which is not drained by a proper drain pipe. Outboard valve casings below sea valves must be covered *where possible* with non-conducting material, such as sawdust or manure, temporarily boxed in.

(6) The gages and oil cups will not be removed.

(7) The sea valves must be closed and properly secured.

(8) The storerooms must be cleaned.

TABLE II.

PROPERTIES OF SATURATED STEAM.

BRITISH UNITS.

Pressure in Pounds per Square Inch, absolute.	Temperature of Boiling Point, Degrees Fahr.	Sensible Heat of the Liquid, above 32° Fahr.	Total Heat, above 32° Fahr.	Latent Heat, or Heat of Vaporization.	Specific Volume, or Volume of One Pound of Steam in Cubic Feet.	Density, or Weight, in Pounds, of One Cubic Foot.
1	102.0	70.0	1113.1	1043.0	334.6	0.00299
5	162.3	130.7	1131.5	1000.8	73.22	0.01366
10	193.3	161.9	1140.9	979.0	38.16	0.02621
14.7	212.0	180.8	1146.6	965.8	26.64	0.03758
15	213.0	181.8	1146.9	965.1	26.15	0.03826
20	228.0	196.9	1151.5	954.6	19.91	0.05023
25	240.0	209.1	1155.1	946.0	16.13	0.06199
30	250.3	219.4	1158.3	938.9	13.59	0.07360
35	259.2	228.4	1161.0	932.6	11.75	0.08508
40	267.1	236.4	1163.4	927.0	10.37	0.09644
45	274.3	243.6	1165.6	922.0	9.287	0.1077
50	280.9	250.2	1167.6	917.4	8.414	0.1188
55	286.9	256.3	1169.4	913.1	7.696	0.1299
60	292.5	261.9	1171.2	909.3	7.096	0.1409
65	297.8	267.2	1172.7	905.5	6.583	0.1519
70	302.7	272.2	1174.3	902.1	6.144	0.1628
75	307.4	276.9	1175.7	898.8	5.762	0.1736
80	311.8	281.4	1177.0	895.6	5.425	0.1843
85	316.0	285.8	1178.3	892.5	5.125	0.1951
90	320.0	290.0	1179.6	889.6	4.858	0.2058
95	323.9	294.0	1180.7	886.7	4.619	0.2165
100	327.6	297.9	1181.9	884.0	4.403	0.2271
105	331.1	301.6	1182.9	881.3	4.206	0.2378
110	334.6	305.2	1184.0	878.8	4.026	0.2484
115	337.9	308.7	1185.0	876.3	3.862	0.2589
120	341.1	312.0	1186.0	874.0	3.711	0.2695
125	344.1	315.2	1186.9	871.7	3.572	0.2800
130	347.1	318.4	1187.8	869.4	3.444	0.2904
135	350.0	321.4	1188.7	867.3	3.323	0.3009
140	352.9	324.4	1189.5	865.1	3.212	0.3113
145	355.6	327.2	1190.4	863.2	3.107	0.3218
150	358.3	330.0	1191.2	861.2	3.011	0.3321
155	360.9	332.7	1192.0	859.3	2.919	0.3426
160	363.4	335.4	1192.8	857.4	2.833	0.3530
165	365.9	338.0	1193.6	855.6	2.751	0.3635
170	368.3	340.5	1194.3	853.8	2.676	0.3737
175	370.7	343.0	1195.0	852.0	2.603	0.3841
180	373.0	345.4	1195.7	850.3	2.535	0.3945
185	375.2	347.8	1196.4	848.6	2.470	0.4049
190	377.4	350.1	1197.1	847.0	2.408	0.4153
195	379.6	352.4	1197.7	845.3	2.349	0.4257
200	381.7	354.6	1198.4	843.8	2.294	0.4359
205	383.8	356.8	1199.0	842.2	2.241	0.4461
210	385.9	358.9	1199.6	840.7	2.190	0.4565
215	387.9	361.0	1200.2	839.2	2.142	0.4669
220	389.8	363.0	1200.8	837.8	2.096	0.4772
225	391.8	365.1	1201.4	836.3	2.051	0.4876
230	393.7	367.1	1202.0	834.9	2.009	0.4979
235	395.6	369.0	1202.6	833.6	1.968	0.5082
240	397.4	371.0	1203.2	832.2	1.928	0.5186
245	399.2	372.8	1203.7	830.9	1.891	0.5289
250	401.0	374.7	1204.2	829.5	1.854	0.5393
255	402.7	376.5	1204.8	828.3	1.819	0.5496
260	404.5	378.4	1205.3	826.9	1.785	0.5601
265	406.2	380.2	1205.8	825.6	1.753	0.5705
270	407.9	381.9	1206.3	824.4	1.722	0.5809
275	409.5	383.6	1206.8	823.2	1.691	0.5913

TABLE II.—Continued.

Pressure in Pounds per Square Inch, absolute.	Temperature of Boiling Point, Degrees Fahr.	Sensible Heat of the Liquid, above 32° Fahr.	Total Heat, above 32° Fahr.	Latent Heat, or Heat of Vaporization.	Specific Volume, or Volume of One Pound of Steam in Cubic Feet.	Density, or Weight, in Pounds, of One Cubic Foot.
280	411.1	385.3	1207.3	822.0	1.662	0.602
285	412.7	387.0	1207.8	820.8	1.634	0.612
290	414.3	388.6	1208.3	819.7	1.607	0.622
295	415.9	390.3	1208.8	818.5	1.580	0.633
300	417.4	391.9	1209.3	817.4	1.554	0.644
305	418.9	393.5	1209.7	816.2	1.529	0.654
310	420.4	395.0	1210.2	815.2	1.505	0.664
315	421.9	396.6	1210.6	814.0	1.481	0.675
320	423.4	398.1	1211.1	813.0	1.459	0.685
325	424.8	399.6	1211.5	811.9	1.437	0.696
330	426.2	401.1	1211.9	810.8	1.415	0.707
335	427.6	402.6	1212.4	809.8	1.395	0.717

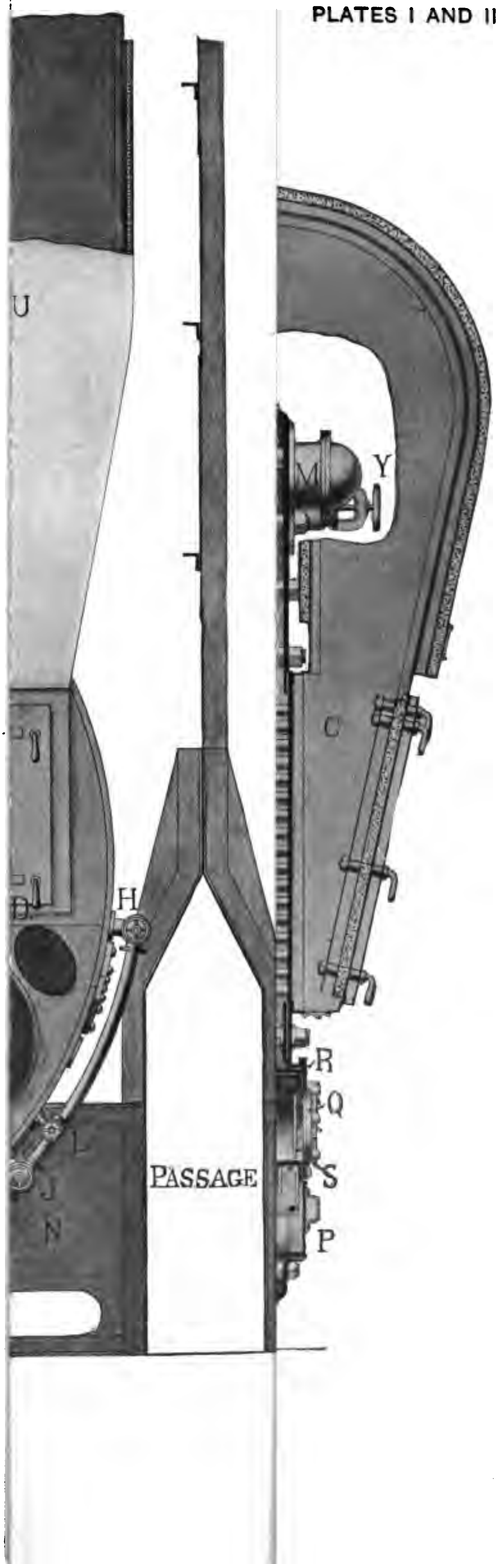
TABLE III.

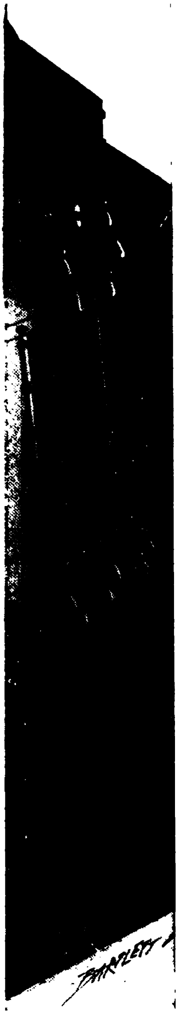
Vacuum in Inches of Mercury.	Absolute Pressure in Inches of Mercury.	Absolute Pressure in Pounds per Square Inch.	Temperature of Boiling Point, Degrees Fahr.	Sensible Heat of Liquid, above 32° F.	Total Heat above 32° Fahr.	Latent Heat, or Heat of Vaporization.	Specific Volume, or Volume of 1 Pound Steam in Cubic Ft.	Density, or Weight of 1 Cubic Foot.
....	....	.085	32.0	0	1091.7	1091.7	3387.	0.000295
29.5	.5	.245	59.0	27.12	1099.9	1072.8	1276.	0.000783
29.	1.0	.490	79.2	47.29	1106.1	1058.8	660.	0.00152
28.5	1.5	.735	91.9	59.93	1110.0	1050.1	448.5	0.00223
28.	2.	.980	101.3	69.31	1112.8	1043.5	341.2	0.00293
27.5	2.5	1.225	108.1	76.1	1114.9	1038.8	281.9	0.00355
27	3	1.47	115.2	83.2	1117.1	1033.9	232.3	0.00431
26	4	1.96	125.5	93.6	1120.2	1026.6	177.1	0.00565
25	5	2.45	133.8	102.	1122.7	1020.7	143.5	0.00697
24	6	2.94	140.8	109.	1124.9	1015.9	120.8	0.00828
23	7	3.43	146.9	115.2	1126.7	1011.5	104.3	0.00958
22	8	3.92	152.3	120.6	1128.4	1007.8	91.97	0.01087
21	9	4.41	157.1	125.5	1129.9	1004.4	82.87	0.01214
20	10	4.90	161.5	129.9	1131.2	1001.3	74.60	0.01341
19	11	5.39	165.5	133.9	1132.4	998.5	68.26	0.01465
18	12	5.88	169.3	137.7	1133.6	995.9	62.81	0.01594
17	13	6.37	172.8	141.3	1134.6	993.3	58.14	0.01717
16	14	6.86	176.0	144.5	1135.6	991.1	54.40	0.01838
15	15	7.35	179.1	147.6	1136.5	989.0	50.95	0.01962
14	16	7.84	182.0	150.6	1137.5	986.9	47.97	0.02085
13	17	8.33	184.8	153.4	1138.3	984.9	45.28	0.02209
12	18	8.82	187.4	156.0	1139.1	983.1	42.93	0.02330
11	19	9.31	189.9	158.5	1139.9	981.4	40.81	0.02450
10	20	9.80	192.3	160.9	1140.6	979.7	38.90	0.02572
8	22	10.78	196.8	165.5	1142.0	976.5	35.56	0.02812
5	25	12.25	203.0	171.7	1143.9	972.2	31.52	0.03176
0	30	14.7	212.0	180.8	1146.6	965.8	26.60	0.03760

From Peabody's tables, arranged by temperatures, by interpolation.
14.7 pounds = 30, or 29.922 inches exactly, or 1 pound = .204 inches.

INDEX.

PLATES I AND II.





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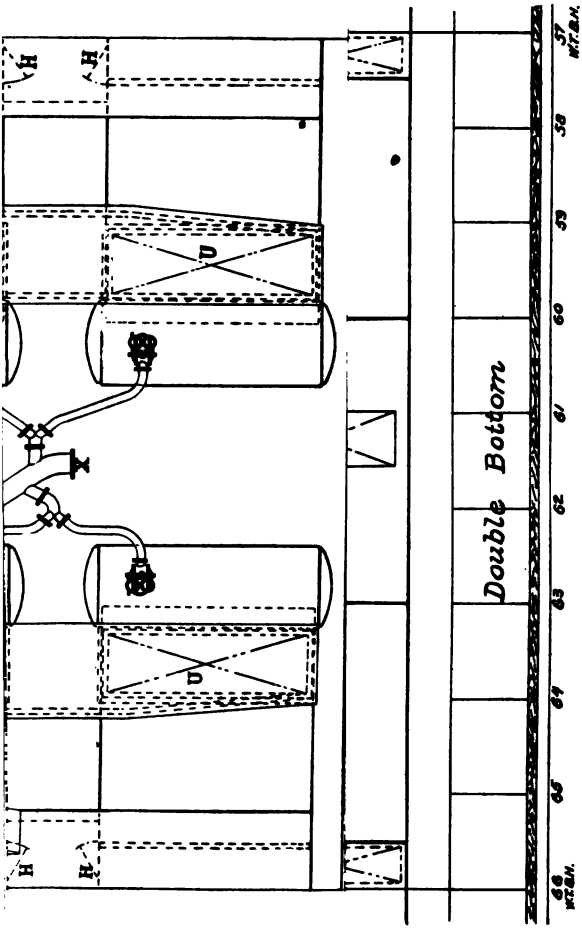

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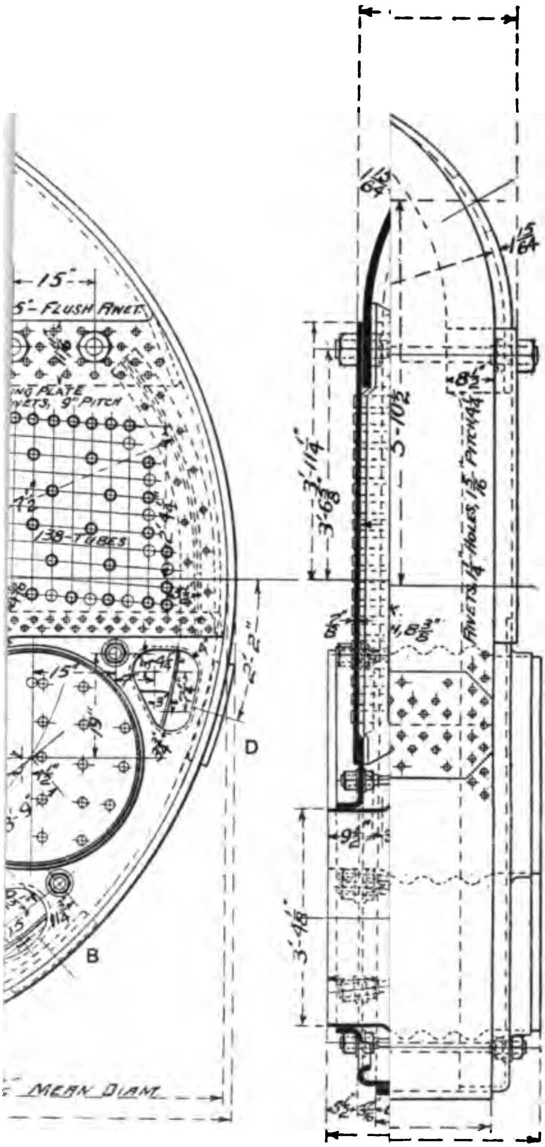

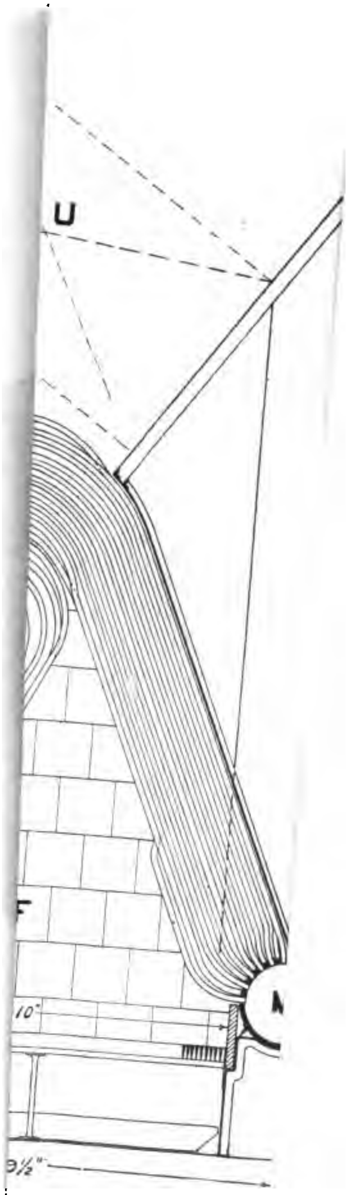
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PLATE XIII.

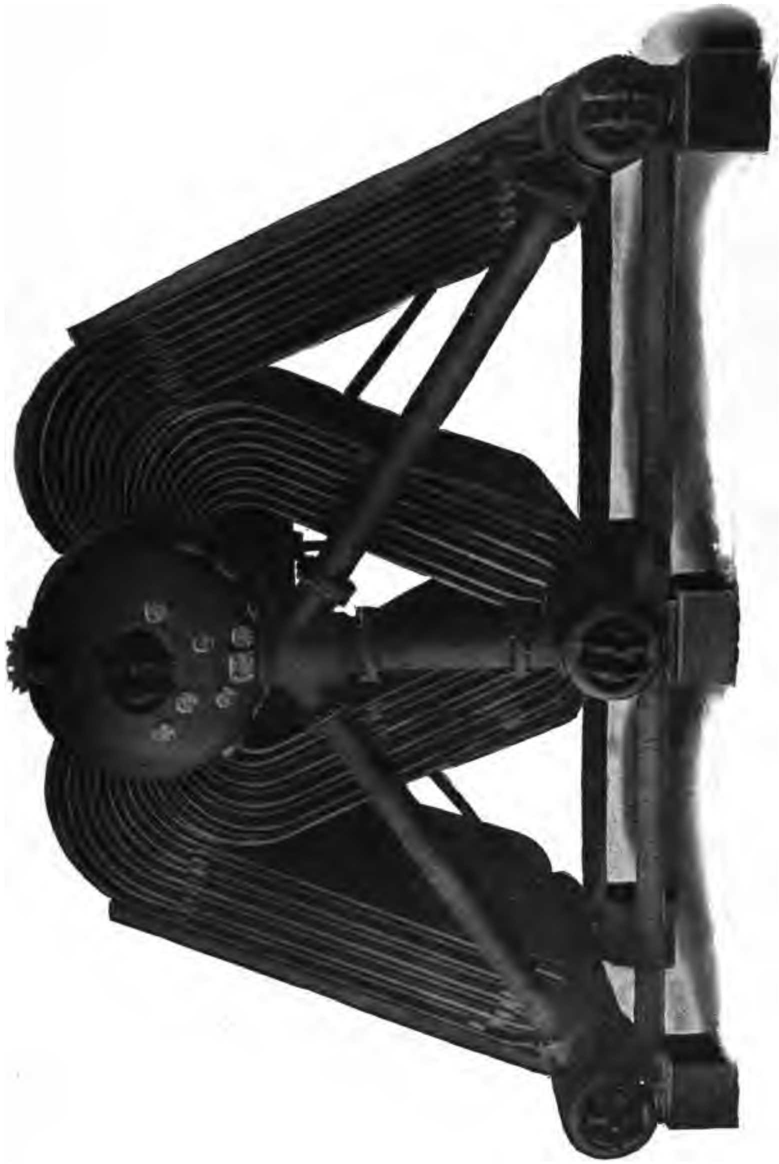

PLATE XIV.

Date Loaned

N° 4			

Demco 292-5